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LAMP MANUFACTURE AND VITAMINE RESEARCH

by A. VAN WIJK. 535.61-31 : 621.327.31 : 612.392.01

In this article it is shown how in the Philips Laboratory the problem of formulating the requirements to be met with sources of ultraviolet radiation in view of their application has led to research on vitamines, and particularly to new ideas about vitamine D.

Introduction

If the human or animal diet is deficient in certain organic substances the health of the human being or animal will suffer. These generally quite complex substances are necessary only in extremely small amounts and are called *vitamines*. Vitamines have become familiar to the general public within a very short time. Although the idea of malnutrition due to their lack was introduced into the science of health only a few decades ago, almost everyone is now acquainted with the terms vitaminosis and deficiency diseases and realizes that the former are essential for preventing the latter. It will, however, probably be a surprise to many that a lamp factory may be concerned with vitamines, as the title of this article suggests. It is our intention to show how it came about naturally that the Philips Laboratory began to work on vitamines, and how this work resulted in investigations which led to deeper insight into the subject.

Ultraviolet radiation

The invisible ultraviolet radiation forms the direct connection between the lamp factory and the subject of vitamines. Since the beginning of the present century ultraviolet radiation has been playing an increasingly important part in medicine and biology. It is not only true that a great many diseases can be cured by irradiation of the patient with ultraviolet light, the significance of this radiation for health is even greater, since a certain minimum dosage of ultraviolet light may be regarded as essential for the maintenance of good health. The sun is the natural source of this light. Ultraviolet radiation is thus a necessity of life, and when this necessity is not supplied deficiency phenomena appear. Various diseases, including infectious diseases, are particularly apt to occur after a continued lack of ultraviolet light, for example toward the end of winter, when the sun gives little or no active ultraviolet radiation. Certain diseases are called "diseases of the dark", because they occur or are promoted by habits of living or circumstances in which too little light — and in this connection especially ultraviolet light — is received. Among these are rickets, scrofula and tuberculosis.

Since the natural source of the necessary ultraviolet radiation, the sun, has been found to fall short, particularly in the winter and in our climate, use has been made of artificial sources of radiation to supply the deficiency. In the first place this was done in purely therapeutic cases, but as the realization of the necessity of ultraviolet radiation for the healthy individual gained ground, such sources began to be employed for protection against disease, as a prophylactic or, one might say, as a measure of hygiene. It will be clear that this presents a problem to the lamp factory laboratory. What are the requirements which a lamp must satisfy in order to replace the sun when used as a hygienic measure? What must be the nature of the radiation emitted and how intense must it be? It must be kept in mind that ultraviolet radiation is a collective term for all the radiation with a wave length between 400 and about 185 mμ (shorter wave lengths also, although they may be excluded immediately, since they do not penetrate through the atmosphere). The ultraviolet radiation from the sun is confined to the longer wave lengths, and the shortest wave length occurring in the sun's spectrum depends upon the part of the earth's surface and the season of the year. It is, however, never below about 290 mμ. It is therefore certain that a source of radiation which must substitute the sun need give no radiation with a wave length less than 290 mμ. It is, however, another question whether it is permissible for it to do so; in other words whether there would be disadvantages if it did. Further there is the question whether it is actually necessary that radiation with a wave length in the neighbourhood of 290 mμ be present, or whether it is sufficient to have only longer waves?

Direct observation can supply answers to the above questions only imperfectly and incompletely. Since we are here concerned with the prophylactic action on persons in good health, the wide deviations existing among such persons necessitate a statistical treatment so extensive that is rarely possible to be carried out.

One general conclusion can, however, be accepted with confidence, and that is that practically all the beneficial action of every source of radiation is lost if the radiation is filtered through ordinary glass. Whereas ordinary glass transmits a large part of the radiation with a wave length greater than about 320 mμ, but absorbs shorter wave lengths to a large extent, the effectiveness of ultraviolet light thus appears to be chiefly confined to the radiation having a wave length shorter than about 320 mμ. A further reaching conclusion may be arrived at by closer study of a single definite effect of the ultraviolet light, an effect which is distinguished from most of its other effects by the fact that the mechanism has to a large extent been clarified, and therefore lends itself to the study of specific questions.

Rickets (rachitis) and ultraviolet radiation

The above-mentioned effect is the prevention and cure of rickets. This is a disease of the growing skeleton, and there fore a children's disease, the main feature of which is that the newly formed bone tissue does not calcify but remains soft.

As a result deformities may appear as bowlegs and knock knees, too narrow a pelvis or chest, curvature of the spine, etc.

On the basis of the research of Mc Collum and others, rickets was known to be a deficiency disease caused by the lack of a certain vitamine which should be present in cod liver oil and was called vitamine D. Only a few natural foods contain vitamine D in amounts of any importance. This fact explains the widespread occurrence of the disease in children, when no preventive measures are taken. Huldschinsky now observed that rachitic children could be cured by irradiation with a quartz mercury lamp ("sunlight lamp treatment") just as well as they were cured by administration of a substance containing vitamine D. The further study of this very interesting dualism in the cure of rickets was greatly simplified by the fact that experiments could be carried out on animals, in this case young rats, which can be rendered rachitic by means of an experimental diet of a definite composition. It soon appeared that animals which received this diet, but which were at the same time irradiated with ultraviolet light, developed no rickets. This was also the case, when a sufficient amount of a substance containing vitamine D was added to their diet. Vitamine D and ultraviolet light appeared therefore to be equivalent, although at first the connection between them was not evident. The explanation was found after Steenbock and Hess discovered that ultraviolet light had the same effect when, instead of the animals themselves, their food was irradiated. This irradiation gave the food the properties of a substance containing vitamine D, that is, vitamine D was formed in the food under the influence of ultraviolet light from some component which was originally inactive. In a remarkably short time further facts were established about this component which was indicated by the name *provitamine D.*

Provitamine D

In the beginning the provitamine D was thought to be identical with *cholesterol* (Hess). Cholesterol is a very common component of animal fats. When separated from the other components, and after having been irradiated with ultraviolet light, it was actually found to exhibit the action of vitamine D. At the same time Hess and Weinstock were able to show that irradiation caused a physically observable change in cholesterol: an absorption band in the ultraviolet at about 300 mμ gradually disappeared.

Various other sterols and cholesterol derivatives were investigated by Rosenheim and Webster with a view to their possible activation. They found that irradiated ergosterol is very active compared with irradiated cholesterol.

In addition they ascertained that rigorously purified cholesterol had lost its activatability, so that it was not the cholesterol itself, but an impurity which must be considered to be the provitamine. This conclusion was also reached by Pohl and Windaus, who studied the change in the absorption of cholesterol upon irradiation more quantitatively. Cholesterol purified in a certain way, and no longer capable of being activated, also failed to show the characteristic absorption bands between about 270 and 300 mμ.

On the basis of the sensitivity of provitamine D to certain chemical treatments (bromination and de-bromination, oxidation) it was considered possible that ergosterol, occurring as an impurity in natural cholesterol, was the provitamine. Ergosterol was actually found to give the characteristic absorption bands which are also shown by the cholesterol, when not specially purified and still capable of being activated. The ergosterol, however, exhibited much more intense absorption: about 0.5 mg of ergosterol gave an absorption of the same order of magnitude as 1 gram of cholesterol dissolved in an equal amount of solvent, and with the same thickness of layer. When it was then found that after irradiation the 0.5 mg ergosterol was also equivalent to 1 gram of cholesterol for the cure of rachitic rats, the conclusion seemed to be obvious. There was, however, a fault in the logic which remained unnoticed for many years. It had indeed been proved that ergosterol receives antirachitic properties by irradiation with ultraviolet light, and further, that in this case no impurity of the ergosterol must be considered responsible, a fact which we shall not discuss in this article. Ergosterol therefore may with truth be called provitamine D. From this, however, it by no means follows that the impurity of cholesterol with provitamine D properties is actually ergosterol. It was only shown that the provitamine D in cholesterol has a similar absorption spectrum to that of ergosterol, and in the same way as ergosterol is sensitive to certain chemical treatments.

Although the conclusion seemed very seductive and plausible, and although it was accepted for nearly 10 years explicitly or implicitly by science, it has been found to be incorrect. It has been found that ergosterol is not the only provitamine D, and, especially, that it is not the provitamine which occurs in cholesterol. This fact in no way detracts from the value of ergosterol as provitamine D or from that of the vitamine D obtained from it as a preventive against rickets in children or rats or pigs, nor from most of the scientific research on the photochemistry of vitamine D formation. It would lead us too far afield if we were to explain precisely how one was gradually brought to this conclusion. It will suffice here to state that the credit of being the first to formulate this fact is due to Waddell, on the basis of a series of very fine experiments on chicks, in which it was found that the effect of a definite amount of irradiated cholesterol was much greater on these animals than that of an amount of irradiated ergosterol which was equivalent to the cholesterol in the case of rachitic rats 1).

In order to demonstrate the great similarity between the absorption spectra of the provitamine in cholesterol and of ergosterol, *table I* and *fig. 1* show one of our measurements on these spectra. In the table below is given the absorption index for various wave lengths of a solution of cholesterol containing the provitamine which had been repeatedly purified by recrystallization ($a_{\text{chol}+\text{pr}}$).

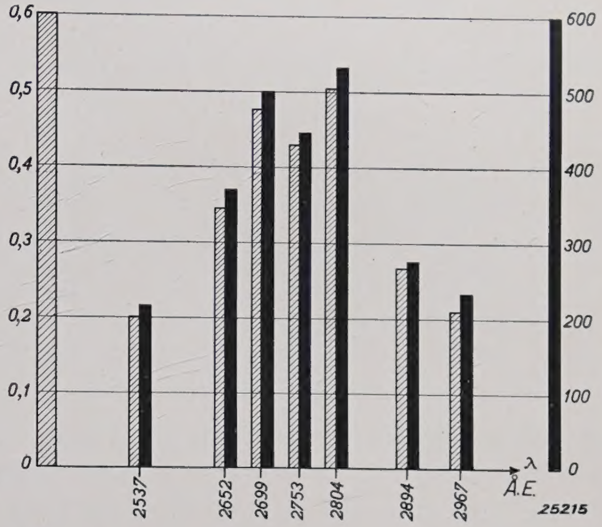

Fig. 1. Comparison of the absorption indices of provitamine in cholesterol (cross-hatched) and of ergosterol (black) for various mercury lines.

This absorption index a is defined by $I/I_0 = e^{-acd}$, where I_0 and I are the intensities of the incident and transmitted radiation respectively with a thickness of layer d (in mm) and a concentration c (as unit of concentration 80 g/liter was used). By repeated irradiation, treatment with absorption charcoal and repeated recrystallization, cholesterol containing no provitamine is obtained (a_{chol}). The difference between the absorption indices before and after the treatment gives the absorption index of the provitamine (a_{pr}) multiplied by its unknown concentration in the cholesterol (c_{pr}). A comparison of the value obtained with the absorption index of ergosterol (a_{erg}) gives a ratio which is very nearly independent of the wave length. If

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1) The vitamine D obtained from an impurity of cholesterol and that obtained from ergosterol are therefore different substances, both of which show antirachitic activity. If one compares quantities of the two substances which have the same antirachitic action on rats, the first substance has a much stronger action on chicks than the other. At the end of this article the experiments on chicks are discussed as well as the difference between the two kinds of vitamine D(cf. page 38).

we assume not only that the form of the provitamine spectrum is similar to that of the ergosterol spectrum, but also that the absolute magnitude of the absorption is the same, the constant ratio indicates the concentration of the provitamine in the cholesterol.

Table I. Comparison of the absorption spectra of provitamine in cholesterol and of ergosterol.

λ mμ	$a_{\text{chol + pr}}$	a_{chol}	$a_{\text{chol + pr}} - a_{\text{chol}} = = a_{\text{pr}} \cdot c_{\text{pr}}$	a_{erg}	$\frac{a_{\text{pr}} \cdot c_{\text{pr}}}{a_{\text{erg}}}$
296.7	0.233	0.019	0.214	232	0.00092
289.4	0.286	0.022	0.264	278.5	0.00094
280.4	0.536	0.028	0.508	530.5	0.00095
275.3	0.559	0.028	0.431	441.5	0.00097
269.9	0.525	0.050	0.475	499	0.00095
265.2	0.438	0.089	0.349	370.5	0.00094
253.7	0.370	0.065	0.205	212	0.00096

Photochemistry of vitamine D formation; connection with the requirements for sources of ultraviolet light

After this digression on provitamine D, let us return to the point in the argument where we stated that rickets can be prevented (or cured) on the one hand by irradiation of the test animals, and on the other hand by irradiation of their food. The link between these two statements lies in the fact that the skin (of human beings as well as of rats, pigs or chicks) contains cholesterol which, because of its content of provitamine D, can be rendered antirachitic in action. The vitamine D so formed can be taken up by the body from the skin, just as it can be taken from the food. In this way is explained the apparent dualism of rachitis — a deficiency disease due to lack of vitamine D, avitaminosis or hypovitaminosis on the one hand, and on the other hand a "disease of the dark". At the same time this is a case (the only one up to now) of the action of ultraviolet light on the human (and animal) organism in which the primary process taking place in the skin is known, and permits of closer study in the laboratory. As far as measures against rickets are concerned, therefore, the question as to the most favourable composition of the light of a "hygienic" ultraviolet light source comes down to the question of the best composition for the radiation in the photochemical formation of vitamine D from provitamine D.

In our investigations of this question [2]) we found that the composition of the radiation is by no means unimportant. These investigations were carried out in the first place on the provitamine ergosterol, and were later repeated as far as necessary on other provitamines D. The results are the same with the different provitamines D, a fact which was to be expected on the grounds of the similarity of their absorption spectra in the ultraviolet region. On the one hand the absorption spectrum determines the radiation which can be absorbed and therefore which can be active, and on the other hand the nature of the atomic bonds in the molecule, and thus the possible transitions due to the absorption of radiation, are expressed in the absorption spectrum.

For the study of the transformations taking place extensive use was made of the observation of the changes occurring in the absorption spectrum. For the purpose of irradiation the provitamine was dissolved in a suitable inactive solvent with a high transparency in the ultraviolet (especially purified hexane, ether or alcohol). It was found necessary to remove all oxygen before irradiation, also that dissolved in the solvent, as otherwise oxidized and inactive reaction products were obtained (for the technique and that of the determination of the absorption spectra the reader is referred to the publications mentioned in the footnote). After having been irradiated for some time a part of the provitamine will be changed into one or more reaction products which in turn may be liable to further change.

If the absorption spectrum of such a solution is measured, it represents in general the spectrum of a mixture of substances. One of these is known, namely the provitamine. The amount of provitamine in the mixture which has not been changed can be determined with the aid of digitonine. (Digitonine gives with the provitamine an addition product insoluble in alcohol, while it does not with the reaction products). By subtracting from the absorption found for the mixture the part due to the provitamine still unattacked, the absorption of the mixture of the reaction products is obtained. For each case this can be recalculated to give that which would be found for any arbitrarily chosen concentration, that is the specific absorption of the reaction mixture. The result of measurement and calculation now depends closely upon the composition of the radiation used for bringing about the reaction. It was found possible to distinguish between two typical kinds of active radiation mixtures, namely:

a) that in which only radiation with a wave length greater than about 280 mμ acts; this will henceforth be called "long wave" radiation,

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[2]) E. H. Reerink and A. van Wijk, Proc. Kon. Acad. Wet. **32**, 845, 1929; Bioch .J. **23**, 1294, 1929; Bioch. J. **25**, 1001, 1931; Chemistry at the Centenary (1931) Meeting Brit. Ass.; E. H. Reerink, A. van Wijk and J. v. Niekerk, Chem. Wbl. **29**, 645, 1932.

b) that in which only radiation with a wave length of about 250 mμ acts, which we will call "short wave" radiation.

The mixture indicated under a) was obtained by filtering the radiation of a quartz mercury lamp (mercury vapour pressure of the order of 1 atmosphere [3])) through a solution of benzene or xylene in alcohol, which absorbs the radiation of wave lengths shorter than about 272 and 284 mμ respectively.

For the "short wave" radiation use was made of a low pressure column discharge in mercury vapour, which emits almost exclusively the two resonance lines of mercury. By filtering the radiation through an absorption cell filled with chlorine gas the active radiation was practically limited to the resonance line with a wave length of 253.7 mμ.

It was now found that with "long wave" irradiation the reaction proceeds quite simply, at least as long as the transformation is not carried too far: the specific absorption a_R of the reaction mixture in the latter case then no longer depends upon the degree of decomposition (cf. *table II*). In other words the reaction may be described as if primarily only one reaction product is formed, which is then changed in its turn only after long continued irradiation. Or a mixture of reaction products may be formed whose amounts are in a constant ratio to each other independent of the degree of decomposition (when the reaction has not proceeded too far), that is to say that it is more probable that the products are formed simultaneously than that they are formed successively one from the other. The simple process described holds approximately up to a degree of decomposition of the order of 60 per cent.

Table II. Absorption spectra of "long wave" irradiated ergosterol solutions at different degrees of decomposition.

			Degree of transformation					
			10.4 %		23.5 %		31.4 %	
λ mμ	a_{erg}	a_R, long wave	$a_{calc.}$	$a_{exp.}$	$a_{calc.}$	$a_{exp.}$	$a_{calc.}$	$a_{exp.}$
313.0	0.7	25	3	2	6	6	8	10
302.2	27	87	33	31	41	41	45	47
296.7	232	172	226	222	218	217	213	215
289.4	278	264	277	274	275	274	274	275
280.4	530	395	517	515	499	494	488	489
275.3	441	418	439	438	436	433	435	436
269.9	499	452	494	495	488	484	484	485
265.2	370	442^5	387	377	384	387	393	389
253.7	212	371^5	228	227	249	252	261	272
248.3	144	336	165	165	189	193	205	215

The columns a_{erg} and $a_{R\ \mathrm{longwave}}$ give respectively the absorption indices of ergosterol and of the reactionproduct obtained by longwave irradiation (both a mean of a great number of measurements). The following columns give the agreement between the absorption values obtained in a definite set of measurements and the calculated values according to $a_{calc} = (1 - a)\ a_{erg} + a\ a_{R\ \mathrm{longwave}}$, where a is the degree of the decomposition.

The primary reaction product of the "long wave" irradiation could be separated from the unattacked ergosterol by carrying out the necessary operations in a vacuum (precipitation of the ergosterol with digitonine, recrystallization). The crystalline substance obtained possessed an antirachitic activity of an intensity which had up to then never been found namely 26.9 × 10^3 I.U.D. (International Units Vitamine D) per milligram [4]). Since it was later found possible by chemical methods (esterisation with 3.5 dinitrobenzoic acid, recrystallization and saponification) to obtain a crystalline substance from the irradiation product of ergosterol, which was called calciferol, and which had a still higher activity (about 40 × 10^3 I.U.D. per mg), and must be considered to be pure vitamine D from ergosterol, it follows that the crystalline reaction product obtained directly by "long wave" irradiation was not yet pure vitamine D, although its content of the latter was very high.

The reaction with "short wave" irradiation proceeds in quite a different way. The specific absorption of the reaction mixture depends closely, even when the change is still small, on the degree of transformation, the spectra found differ widely from those of the "long wave" product and the antirachitic activity is much lower. For the purpose of comparison in *table III* and *fig. 2* the spectrum is given of the reaction product obtained after 30 per cent transformation with "short wave" radiation. The activity per mg was in this experiment about 11.5 × 10^3 I.U.D./mg. The content of vitamine D is therefore much lower than after "long wave" irradiation. This indicates that a large part of the provitamine has heen changed into other products than vitamine D. In other words the "short wave" radiation is unfavourable for the formation of vitamine D.

As to the question of the most favourable composition of the radiation for a lamp of hygienic value, it follows from the foregoing that absence of "short wave" radiation which does not occur in the sun's spectrum is to be desired, since the prevention of rickets is one of the chief demands made on such a lamp. On the basis of the absorption spectrum of ergosterol (or of another provitamine D) it again follows that only radiation with a wave length less than about 310 mμ can be effective, since only such radiation is absorbed. These considerations have led to the introduction of a special kind of glass, which transmits in the ultraviolet down to about 280 mμ, but which absorbs the "short wave" region, as a container for the lamps which must serve to replace the sun (cf. Philips techn. Rev. **2**, 18, 1937, filter for "Biosol").

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[3]) For the spectrum compare Philips techn. Rev. **2**, 18, 1937, spectrum of the Philips "Biosol".

[4]) By international agreement the effect tested on rats of a definite amount of an arbitrary but well defined preparation, prepared in the laboratory of the "Medical Research Council" is accepted as a unit. The following may serve to give an idea of this unit. A dosage of about 800 I.U.D. per day is considered suitable for prevention of rickets in nursing children.

Table III. Absorption spectrum of a "short wave" irradiated ergosterol solution at a degree of decomposition of 30%.

λ mμ	$a_{\text{exp.}}$	a_R short wave 30 %
313.0	22	72
302.2	73	180
296.7	263^5	337
289.4	333	460
280.4	554^5	610
275.3	486	589
269.9	530	602
265.2	412	538
253.7	264	385
248.3	199	323

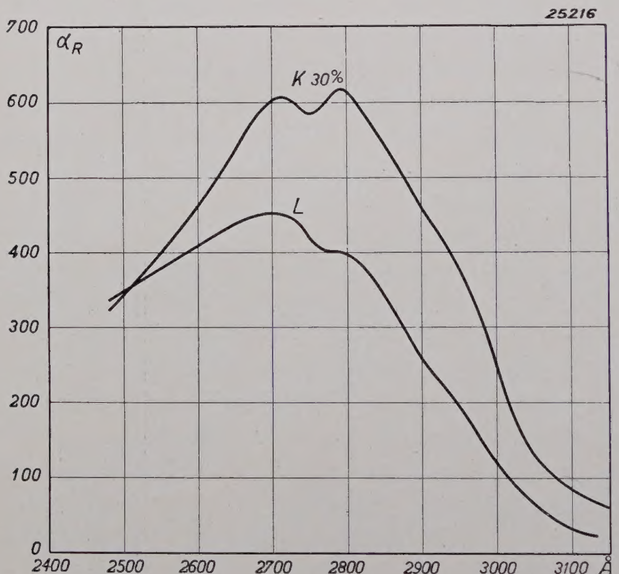

Fig. 2. Absorption index of the reaction product after irradiation of ergosterol as a function of the wave length. *L* irradiation with "long wave" light. The absorption index is independent of the degree of decomposition. *K* irradiation with "short wave" light. The curve reproduced refers to a degree of decomposition of 30%.

Vitamine D and chicks

Rickets is very prevalent among chicks which do not receive sufficient sunlight. This is the case with a large part of the chicks as those are often raised entirely indoors in incubators. Provision must then be made for sufficient addition of vitamine D to their food or for ultraviolet irradiation of the birds themselves. In general an unexpectedly high dosage of vitamine D obtained by irradiation of ergosterol is necessary for the prophylaxis (or therapy) of rickets in chicks. If for example one of two similar groups of chicks is given a certain amount of "natural" vitamine D which is just sufficient, and the other is given an amount of vitamine D from ergosterol which is equivalent to the first when tested on rats, it is found that the action of the latter amount is not sufficient for the chicks. About 25 times as much must be given to obtain the same result. If one now compares in the same way irradiated cholesterol and vitamine D from a natural source, amounts which have equivalent effects on rats are found to be equally effective in the case of chicks (Waddell). We have already given the explanation of this: the provitamine D in cholesterol is not ergosterol. In connection with the great importance of the prevention of rickets in chicks, and in order to remove all doubt about the correctness of the above conclusion, it seemed essential to us to attempt to actually separate the provitamine from cholesterol and to study the properties of the pure substance. All the cholesterols described in the literature contain only extremely slight traces of the provitamine (deduced from the absorption spectrum and the activatability) of the order of 0.1 per cent. Since it did not seem promising to begin with such poor sources of provitamine, we first examined cholesterols from the most varied sources spectro-photometrically for their provitamine content. We finally found a raw material, Chinese duck egg yolk, which contained a cholesterol which was sufficiently rich in provitamine to promise success in its separation. This cholesterol contained about 4 per cent provitamine 5). As a matter of course it had still to be ascertained by comparative chick and rat experiments whether this very unusual cholesterol after irradiation still had the same favourable properties as the more ordinary kind. This was found to be the case.

A method was worked out for the separation in which use was made of fractional adsorption and desorption on aluminium oxide. The solution followed

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5) Boer, Reerink, van Wijk, van Niekerk, Proc. Kon. Acad. Wet. **39**, 622, 1936.

by large quantities of the solvent was filtered through a thick layer of aluminium oxide. The outstreaming liquid was continuously examined by means of absorption measurements, and on the basis of these measurements fractions rich in provitamine and fractions poor in provitamine were separated. Before the cholesterol was subjected to this treatment it was first esterised, with acetic acid for instance. After repeated application of this process to the fraction rich in provitamine a very high concentration was finally obtained. By recristallisation until the properties were constant (absorption spectrum, optical rotation, melting point) the pure acetate of the provitamine was obtained. After saponification and recrystallisation the provitamine itself was obtained and was actually found to differ from ergosterol. It could be identified as 7-dehydrocholesterol. *Table IV* shows the great similarity in the absorption spectra of ergosterol and the provitamine from cholesterol. The provitamine separated from cholesterol as well as the synthetically prepared 7-dehydrocholesterol, exhibit after irradiation the expected high activity with respect to rickets in chicks, with which fact the chain of evidence seems to us to be complete.

Table IV. Comparison of the absorption spectra of ergosterol and provitamine from cholesterol.

λ mμ	a_{erg}	$a_{\text{provit.}}$	$a_{\text{7-dehydrochol.}}$ (synth.)
313.0	0.7	2	0.7
302.2	27	27	26
302.2	27	224	218
289.4	278^0	278	268
280.4	530^0	521	504^0
275.3	441^0	438	424^0
269.9	499	495	473
265.2	370^0	367	354^0
253.7	212	204	202
248.3	144^0	140^0	139

For practical uses [6]) finally other animal sterols, that from the mussel for example, were found to be much more convenient because of their high content of provitamine, which can be activated to "chicken active" vitamine D.

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[6]) The above-described vitamine D preparations for use by human beings as well as for animals are marketed by the N.V. Philips-van Houten company under the general name of "Dohyfral".
The preparation for animals consists of a solution of the "chicken active" vitamine D in oil. The preparations for human consumption are in the form of chocolate tablets which are supplied with "ergosterol vitamine D" as well as with the "chicken active" vitamine D ("Neo-Dohyfral").

PROPERTIES AND APPLICATIONS OF ENAMELLED WIRE.

by J. HOEKSTRA.

621.315.617.4

Enamel lacquer is an excellent insulation material for copper wires because of its high breakdown potential, its high electrical resistance, its slight absorption of water, its unusual thinness and its good mechanical and chemical properties. In this article details are given about these properties of enamel lacquered wire.

Introduction

In electrical engineering the term "enamelled wire" (more accurately "enamel lacquered wire") means metal wire which is insulated by a thin layer of hard baked lacquer. The name often leads to misunderstanding by laymen, who usually think of the glasslike enamel of pots and pans.

The first insulated conductors were made by Faraday when he carried out his pioneer experiments on electromagnetism. According to his diary of 1831 he used "twine and calico". Textiles are thus the oldest form of insulation for wires, and they are still employed on a large scale. Later Werner Siemens used gutta-percha und rubber, which have undoubtedly much higher insulation resistance, but which must be applied in much thicker layers. It is for this reason that insulation materials to be applied in the plastic state, such as rubber, gutta percha and various similar synthetic products of recent years, have no great practical significance for coils and windings. Cotton insulation is also relatively thick, so that the appreciably more expensive silk was often used. The idea, which originated in America around 1900, of applying a thin layer of a lacquer or varnish directly to the copper also was attractive from the point of view of expense.

The idea also was worked out in Germany about 1905. The first task was that of finding a lacquer which was resistant to the chemical influences acting during impregnation and use of the wire, and which in addition was elastic and strong enough for the purpose. Difficulties were encountered at the beginning in satisfying these chemical requirements, since black enamelled wire in particular is made with lacquers having an asphalt base which is not resistant to oil.

In 1906 it was stated [1]) that in Germany copper wire was being made with a coating of cellulose acetate and also of an enamel lacquer. This wire was at first intended for the coils of measuring instruments, etc. but was later available for small machines and transformers.

The early cellulose acetate coatings have almost entirely gone out of use. The lacquers with an asphalt base (for black enamelled wire) have become much less important: all black enamelled wire is not however made with an asphalt base lacquer. Modern enamelled wire is made with the help of oil lacquers. These lacquers consist of mixtures of resins and drying oils (for example wood oil and linseed oil, usually a large proportion of the former in order to produce quick drying, chemically resistant lacquers). Kienle and Adams [2]) give as an example the following composition: 60.5% wood oil, 18.3% raw linseed oil and 21.2% resin neutralized with lime; these components are heated together $1^1/_4$ hours at 270°C, then cooled to 160 ° C and mixed with 10 % benzine and 90% solvent naphtha. It is therefore a very "oily" lacquer, and the oils are already partially polymerized by heating. Of course every manufacturer of enamelled wire uses his own lacquer, the composition of which is usually not published. Artificial resins are also often used in these lacquers.

In the manufacture of enamelled wire a small amount of such a lacquer is applied to the surface of a bare copper wire. This may be done by drawing the wire vertically out of a lacquer container. The wire is then passed through an oven in which the lacquer is "baked". In this process, the polymerisation of the drying oils, which has already begun during the heating of the lacquer, is continued by the oxygen of the air. A strong, cohesive, insoluble layer is the result.

The resins provide for greater hardness of the coating, the (highly polymerized) oil content is responsible for the great elasticity. There is as yet no absolute certainty about structure of the polymerized oils. The properties of the polymer indicate a rubberlike structure, that is a network of quite large molecules are joined to each other at relatively few points. In oil lacquers this structure gives a practically insoluble whole, a fact which indicates very strong, probably chemical bonds at the few points of contact of the large molecules. The presence of the "rubber structure", however, includes the posibility of the swelling of the polymer in liquids whose molecules have the tendency to penetrate between those of the polymer. It may in general be said that great elasticity is very often accompanied by a tendency to swell in suitable liquids. This tendency is very slight with enamel lacquer, but is not entirely absent. Particularly in the case of an insufficiently baked lacquer coating is it noticeable (for instance in the presence of melted beeswax and also benzine at room temperature), it is at a minimum with a normally baked lacquer coating.

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[1]) Electrotechn. Z. **27**, 16, 1906.

[2]) R. H. Kienle and L. V. Adams, Ind. Eng. Chem. **21**, 1279, 1929.

The application of fluid lacquer and the subsequent baking are repeated a number of times (sometimes 6 or even as many as 30 times), until the desired thickness of insulation has been reached. This is done by leading the wire as it comes out of the oven back to the lacquer container and so on.

The application of enamelled wire has become progressively more important in the last few decades. Not only thin and very thin wire (up to 25 microns core diameter; 40 micron wire is used to a large extent at present for high tension transformers) but also the thick kinds (for instance 3 mm core diameter) are at present employed everywhere for transformers, motors, coils, low current cables and connections (telephone installations). The product has at present almost a monopoly in the radio industry (transformers, coils, so-called stranded or "litz" wire), in other branches (motors, power transformers) it is steadily gaining ground. The reasons for this increasing application are the following:

a) The enamel coating has a very high breakdown potential.
b) It has a very high electrical resistance and the dielectric losses are not high.
c) The enamel is an unusually watertight material.
d) The insulation layer is unusually thin.
e) The mechanical properties of the coating satisfy rather high requirements.
f) The enamel coating is very resistant chemically.

We shall examine these characteristics one at a time in order to build up as complete a picture as possible of the final product.

a) Breakdown potential

The breakdown potential of the enamel layer itself may be said to be very high: namely of the order of 10^6 volts/cm for layers from 5 to 20 microns thick.

The breakdown potential of the insulated wire exhibits quite wide variation; the reason for this is that the condition of the metal surface exerts a tremendous influence on breakdown. This phenomenon, which is theoretically perhaps not entirely unexpected with such thin insulating layers, results in the fact that the condition of the bare wire is actually at least as important as that of the insulating layer.

The high breakdown potential of the material is not completely manifested in the finished product because of this influence of the metal surface. Nevertheless the breakdown potentials attained, compared with the thickness of the insulation, are still very high, as may be seen from the table below, in which several of the standard specifications of various countries are noted.

Breakdown potentials (in volts eff), minimum requirements according to the standard specifications of different countries for enamelled wire of various diameters and with an alternating voltage of 50 c/s.

Diameter of wire	Standard thickness of of enamel coating (approx)	Standard Specifications			
		DIN Germany	C 31 France	C 8.7 U.S.A.	BSS 156-Engl. (1936)
mm	microns				
0.1	6	350	150	200	200
0.5	16	500	400	700	1000
0.1	22	750	550	800	1200

The breakdown potential of the various standard specifications are not entirely comparable because the methods of determination differ rather widely. The American and English specifications determine the breakdown of two enamelled wires against each other, the others of one wire against polished metal. Division by two of this "double breakdown" in order to obtain a figure comparable with the other requirement is not permissible, because of the fact that the breakdown found as an average with enamelled wires with different thicknesses of insulation is far from proportional to the thickness of the insulation. This latter fact is again explained by the above-mentioned influence of the metal surface.

Wire with twice the standard thickness of coating exhibits about three times the normal breakdown potential 3).

Fig. 1 which reproduces the result of a large number of determinations of breakdown (DIN method) on two different lots of enamelled wire of the same kind, gives an idea of the relatively wide

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3) By the term breakdown value is meant the voltage which is withstood by 80% of the samples tested, in agreement with the German standard specifications.

variation which occurs as a rule in the determination of this property of enamelled wire. The small difference in the average thickness of the enamel layer found in samples which broke down at widely different potentials, illustrates the fact stated above, that the thickness of the layer of lacquer is by no means the only factor which determines breakdown.

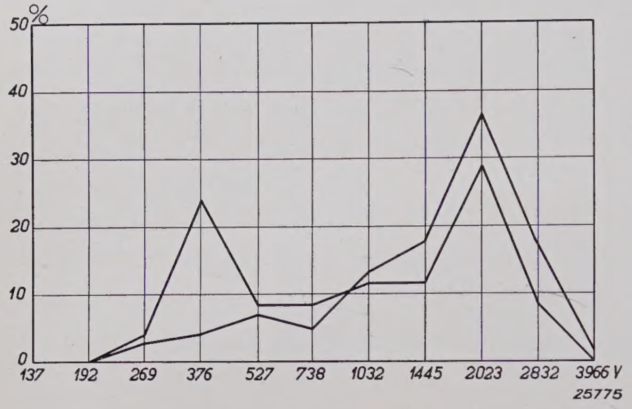

Fig. 1. Statistics of the breakdown potentials measured on two spools of different manufacture (about 60 measurements per spool). The wire was enamelled wire of 0.4 mm core diameter. The thickness of a single layer of lacquer was about 13 μ.

The method was that of the DIN: the wire was wound a bare polished cylinder of 30 mm diameter, and one end was weighted with 50 grams. A sinusoidal alternating voltage of 50 c/s was then applied between the copper wire and the cylinder, and gradually increased from 0 to the breakdown potential. E_{eff} was measured. The breakdown values found were then divided into groups in such a way, that each group begins with a voltage 1.4 times as great as the initial voltage of the previous group. The percentage of the total number of measurements in each group is plotted.

A comparison of the breakdown value of enamelled wire with that of ordinary kinds of wire insulated with textiles is of little value, considering the fact that the textile insulation of these wires, when tested in the unimpregnated condition, has a breakdown potential which is lower than that of the layer of air situated between the textile fibres. The spark travels along the fibres; a breakdown of the insulation material does not take place. This is also shown by the fact that the same breakdown potential may be measured repeatedly at a single point. For example, a wire of $^1/_2$ mm core diameter double covered with cotton (thickness of insulation 120 μ) has a breakdown potential of about 350 volts against a polished cylinder. If a textile wound coil is impregnated, the breakdown potential is somewhat higher, but is entirely dependent on the quality of the impregnation.

b) Insulation resistance and dielectric losses

The enamel layer itself has a very high resistance. With 1000 volts direct voltage on a meter of enamelled wire of $^1/_2$ mm diameter, immersed in mercury, a resistance of 10^{12} ohms is found if the enamel layer has no faults. With standard enamel wire, however, several faults per 10 m are permissible. Such faults are not usually "bare places" while the English expression "pinholes" is also incorrect, but they are spots with an unusually low breakdown potential. If there is such a spot on the wire immersed in mercury, breakdown occurs far below 1000 volts. Another kind of fault which may influence the insulation resistance under certain circumstances is demonstrated by immersion of the wire in water: in this case several otherwise entirely invisible faults are found to exist where the insulation resistance is lower. This holds however only for standard enamelled wire; with extra thick (so-called double-enamelled wire) these faults are practically non-existent. This latter fact, even more than the higher breakdown potential, explains the reason for the increasing demand for extra insulated wire. The "faults" in the insulation described here are of absolutely no importance in the employment of the wire for ordinary coils and transformers because of the fact that with the small number of permissible faults it practically never occurs that two of them lie next to each other. There is a possibility that the faults might be of importance in special applications such as for unimpregnated coils to be used in a moist environment or very low power connections (telephony). In such a case it is better to make sure by using wire with an extra thick enamel layer.

The dielectric loss angle δ, measured at radio frequency, is small ($\tan\delta = 0.015$), and keeps

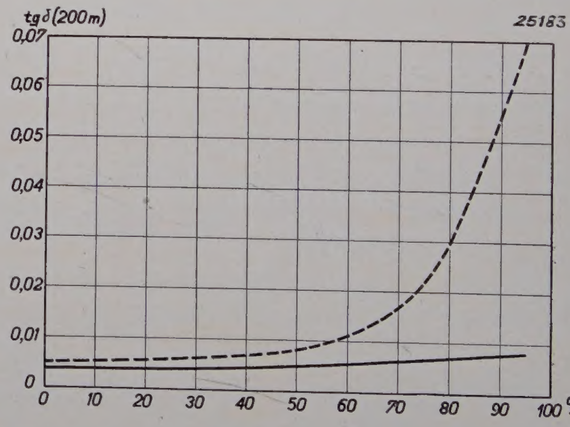

Fig. 2. Dielectric losses ($\tan\delta$) measured at 200 m wave length between two insulated wires with 0.5 mm core diameter, which were twisted together with a pitch of 2.6 cm, as a function of the relative humidity of the surrounding atmosphere. The wires were kept in this atmosphere until the losses had become constant and they were not removed from it for taking the measurements.

———— enamelled wires

- - - - - - wires wound twice with silk.

the same value after long continued storage of the wire in a humidity chamber or moist room. If it is measured while the wire is in an atmosphere of definite relative humidity, the loss angle of enamelled wire is found in practice to increase slightly with the moisture content of the air. *Fig. 2* gives a clear picture of the very favourable behaviour of this material compared with silk. Double silk covered wires and enamelled wires, both with $^1/_2$ mm cores, were twisted together for this purpose with a pitch of 2.6 cm.

The insulation resistance and the dielectric losses are of particular importance when the wire is to be used for cables and for the wiring of apparatus. The application is of great and increasing importance, particularly in telephony. For wiring, enamelled tinned wire is usually used, since tinned wire is more easily soldered.

The dielectric constant is about 3.2, a relatively low value. This is an advantage for the purpose of telephony.

c) Resistance to water

Enamel laquer is an electrical insulation material with an extremely small attraction for water. Because of this characteristic its electrical characteristics remain practically unchanged in very moist surroundings. The insulation value given above of more than 10^{12} ohms may also be measured in water after 48 hours immersion. For wiring in moist surroundings or in a tropical climate enamelled wire is therefore the most suitable. Coils and motors wound with enamelled wire are found to suffer much less from moisture than when wire insulated with textiles and the like is used.

It might be thought that the same resistance to water and moisture could be obtained by soaking paper or textile insulation in impregnating lacquer, that is, also in an oil lacquer, and then baking the whole. This impregnation gives reasonably satisfactory results, but the watertightness of enamel lacquer is not even approached. As an example of this we give the following results of measurements on bifilarly wound coils of 300 double turns with 0.35 mm diameter core, wound on a central core of 3 × 3 cm.

Insulation	Resistance at	
	45% rel. humidity	60% rel. humidity
Enamel lacquer	2×10^{10} ohms	2×10^{10} ohms
Cotton, well impregnated	10^7 ohms	5×10^5 ohms

In the first place the smaller resistance to moisture of the impregnated insulation may be ascribed to the textile or paper fibres which pass straight through the layer of impregnating materials and take up considerable water. In the second place to the fact that baking in this case is carried out at about 100 ° C compared with 300-400 ° C in the case of enamelled wire. In the third place the absorption of water depends also upon the kind of oil in the impregnating lacquer. It is much less for example with wood oil than with linseed oil.

As an example of the second and third points, the table below gives the absorption of water by films of linseed oil and wood oil after 21 days immersion in water [4]) compared with that of a film of enamel lacquer kept for 21 days in an atmosphere saturated with water vapour.

Absorption of water by			
Linseed oil		Wood oil	Enamel lacquer
Dried at room temp.	Dried at 70°C	Dried at room temp.	Baked at 300-400°C
150%	30%	≦ 45%	$1^1/_2$%

In judging these figures it must be kept in mind that the thin films here investigated generally have a higher absorption of water than thick or massive pieces of the same material. Hartshorn, Megson and Rushton [5]) thus found with a film of artificial resin 0.165 mm thick an absorption of water of 3 per cent, while a film 0.675 mm under the same conditions only absorbed 1.94 per cent.

In spite of the slight permeability to water of the enamel layer it is often of importance to impregnate coils which are intended for use in moist surroundings. The purpose of this operation is then, in addition to obtaining a mechanically strong unit, to prevent the penetration of macroscopic amounts of moisture into the coil.

d) Thickness of insulation, "space" factor.

The unusually thin insulation of enamelled wire offers great advantages to the electrical engineer. The "space factor", that is the percentage of the cross section of a wound coil occupied by copper, is at present an important quantity for the constructor, now that every effort is being made to construct electrical apparatus as small as possible.

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[4]) W. Rinse and W. H. G. Wiebols, Verfkroniek, **10**, 231, 250, 1937. Ind. Eng. Chem. **29**, 1149, 1937.

[5]) L. Hartshorn, N. J. L. Megson and E. Rushton, Chem. Ind. **56**, T. 266, 1937.

The space factor is of course dependent on the method of winding, and with completely regular mutual contact of the wires reaches a maximum, which depends then only on the thickness of the insulation. The usual (and in most countries standardized) thicknesses of the commonest wire insulations are given below for wires with core diameters of 1 and 0.3 mm respectively.

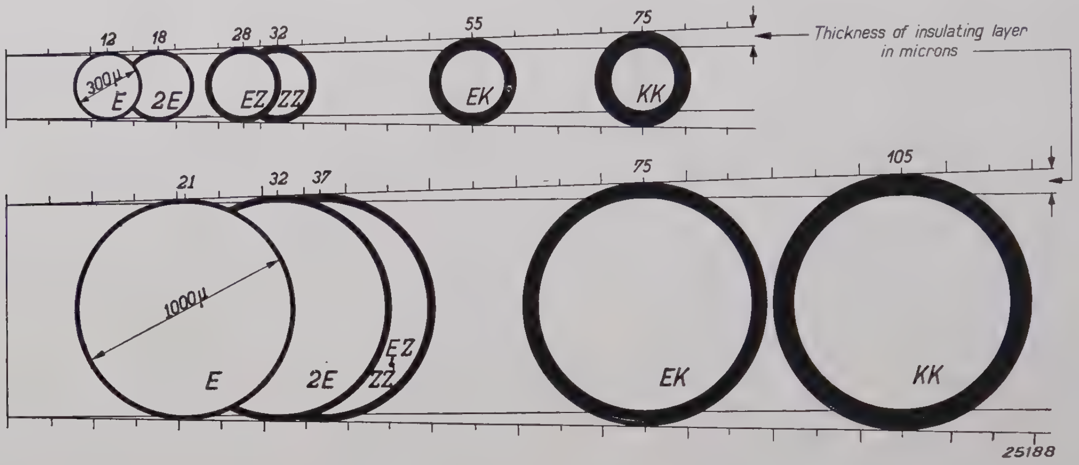

Fig. 3. Thickness of the insulation of ordinary wires for winding.
E = enamelled.
2E = thick enamel layer (twice the normal breakdown potential).
EZ = enamelled and then wound once with silk.
ZZ = bare copper wound twice with silk.
EK = enamelled, wound once with cotton.
KK = bare copper wire, wound twice with cotton.
((In upper right figure) thickness of a single layer of insulation in microns).

e) Mechanical properties of the enamel layer

The mechanical properties of lacquer baked at a high temperature form an interesting subject by themselves. If a piece of enamelled wire is stretched until it breaks, that is, often more than 30 per cent, it is found, except sometimes with very thick layers, that the layer of lacquer is quite undamaged, and that even after this test of strength it can scarcely be removed with the finger-nail.

Most of the wires also easily stand being wound about a mandrel equal in diameter to the wire. In this test the enamel layer is stretched 50 per cent on the outer side. It must, however, be noted that an enamelled wire, which has been wound around a mandrel of such a diameter that the lacquer coating only just remains intact, runs the chance of developing cracks in the coating when the wire is heated in the shape of a spiral (as is done in impregnation). The "critical" mandrel has a diameter 1 to 3 times that of the wire, depending on the material of the wire and the thickness of core and insulation.

Fig. 4 shows a few pieces of standard enamelled wire which have been laid across each other on an anvil and then struck with a hammer. The result gives the impression that the lacquer coating is considerably stronger than the copper beneath it. If, however, the same lacquer films are made on thin copper foil, and the copper is then dissolved in such a way that the enamel lacquer film is not damaged, the stretch of these films by themselves is found to be considerably less than that of enamel layers on copper wire. Several stress-strain diagrams determined with a special dynamometer on such membranes are reproduced in *fig.* 5. The membranes which have a stretch of 19 per cent are decidedly soft ("un-cured"), those with 3.5 per cent stretch correspond to the layers which, on copper have a stretch of 50 per cent.

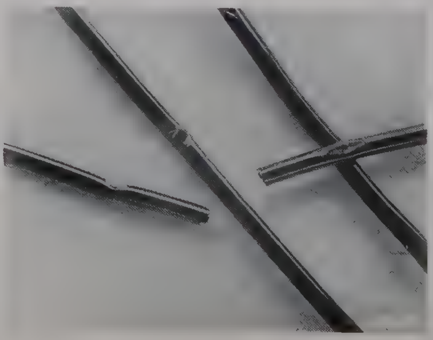

Fig. 4. Several pieces of standard enamelled wire laid across each other on an anvil and then struck with a hammer. The enamel layer shows no injury.

There is therefore no possible doubt that the bond between the lacquer and the copper beneath it is very strong, and that this bond makes possible the great stretch of the layer of lacquer. This also explains why thicker kinds of wire, which have thicker lacquer coatings will withstand less mechanical deformation than thin wires; the great elasticity in the thicker layers can no longer be transferred to the metal *via* the bond to the same degree as is the case with thinner layers of lacquer on thinner wires. Wire 2.5 mm thick, for example, with a lacquer coating of 30 microns will not withstand being wound around a mandrel of its own thickness, although the lacquer is in general softer (less well baked) than with wire of 0.2 mm.

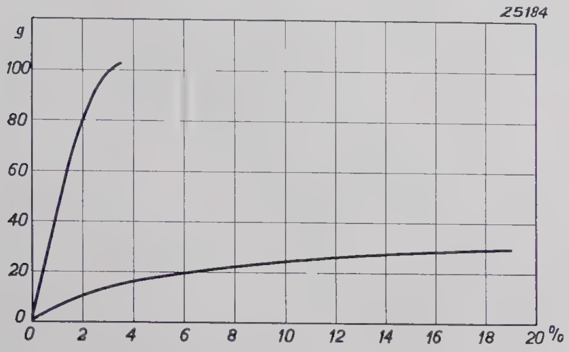

Fig. 5. Stress-strain diagrams of membranes of baked wire enamel. The membranes were baked on copper foil in four steps. each time a given thickness of layer of fluid lacquer was applied and baked a given number of seconds at the same temperature. The copper was dissolved electrolytically. The strips of lacquer film were 5 mm wide and 20 to 30 μ thick. Pieces 5 cm long were stretched about 2.5 mm/min. Upper curve: hard baked, lower curve: soft baked.

The above-mentioned enamelled tinned wire has less favourable mechanical properties with respect to its insulation (mandrel test) than ordinary enamelled wire. The adhesion of the enamel lacquer to tin is much less strong than to bare copper.

f) Chemical properties of the enamel layer

The chemical qualities of the insulating layer, which are important to the electrical engineer, are chiefly stability against aging, sensitivity to temperature, resistance even at high temperature to impregnating substances (paraffin, waxes, asphalts, oil lacquers and other insulating lacquers), to moisture and oils (chiefly transformer and lubricating oil). The requirements of resistance to concentrated alkali and acid solutions, which is still often made, is actually of little importance. The resistance of the enamel to alkalies and especially to acids is high, and can be increased quite easily, although at the expense of the mechanical properties.

The stability of enamelled wire is found to be very high providing the enamel layer has been correctly baked through. In the case of clearly under-baked wire it has sometimes been found after years that the enamel coating had lost some of its elasticity. In the case of standard enamelled wire we have not been able to discover any changes in the course of years.

The sensitivity to high temperatures is slight when the heating is not of long duration. This is obvious considering the high temperature to which the product is exposed during manufacture. No anxiety need be felt for injury to the enamel layer as a consequence of the drying and impregnating of coils at temperatures up to 150 ° C. On the contrary, the heating of enamelled wire from 6 to 24 hours in air at temperatures up to 120 ° C causes a slight further hardening of the enamel layer, which is to be desired for many purposes, and is in fact deliberately brought about by many manufacturers of electrotechnical products.

In the long run the enamel layer has a resistance to high temperature which is as good as, or better than, that of textiles.

The resistance to impregnating materials and lacquers is extremely satisfactory in the case of good modern enamelled wire. Less favourable experiences, which will occasionally be met with in the literature of the last few years, may be ascribed to the fact that the most suitable raw materials were not used for the enamel lacquer.

The so-called finishing lacquer, insulating lacquers which are used cold and only applied to the outside of coils, usually soften the enamel layer temporarily. This is no disadvantage, but serves to bring about a strong adhesion between the dried layer of insulating lacquer. The constructor must of course take this temporary softening into account.

Of the impregnating materials which are applied without solvent (and therefore in a molten state), especially those which contain higher esters have some action on the enamel layer at a high temperature.

Good enamel, however, may be allowed to remain in molten beeswax for 15 minutes or longer at 150 ° C, after which, upon cooling, no depreciation of the enamel can be discovered.

The conducting core

Now that we have studied several characteristics of the layer of enamel lacquer, we shall consider briefly the conducting core of the enamelled wire.

Very much the largest proportion of enamelled wire is electrolytic copper wire. This copper, which has to be very pure to give the highest conductivity required for electrical purposes, has an annealing temperature below 200 ° C. The annealing temperature of a cold worked metal is closely dependent on the degree of deformation; the cold deformation is very great in wire-drawing, considering that this process is at present always carried out as a continuous operation on drawing machines with 10 or more dies, each of which gives the wire an elongation of from 20 to 30 per cent.

The low annealing temperature, which results in enamelled copper being always soft, is due to this cause.

The tensile strength and elongation attained are approximately as follows:

Diameter of wire	Tensile strength	%
mm	kg/mm^2	Stretch
1	23—27	30—40
0.05	27—30	20—26

This annealing of the copper during enamelling is an advantage, in the first place since hard (springy) wire cannot be used for winding coils, and moreover the conductivity of annealed copper is 3 to 4 per cent higher than of copper in the hard state.

With very thin wire, however,the tensile strength of annealed copper is very low for its use in coils. In this case other metals and alloys may be used, although the choice is very much limited by the requirement that the conductivity of the metal chosen may not be very much less than that of copper. Three metals which satisfy this requirement are copper-cadmium (which is also used for overhead high tension lines), silver and copper-silver. The high price of the raw materials silver and copper silver is not all important in this case because of the fairly high cost of working this extremely fine wire. Copper-silver is very strong, but has among other disadvantages a tendency to be corroded by moisture. Copper-silver and silver have little or no stretch in the hard state. They have not reached the annealing point at enamelling temperature. If the material is annealed at a high temperature before enamelling, the advantage of great strength disappears. The absence of stretch is a disadvantage in the use of copper-silver wire on winding machines, since the wire breaks at the slightest irregularity in the winding.

The table below gives a comparison of the properties of thin wire with various core materials.

Core	Diameter of the core	Force at break	Stretch	Specific resist.
	microns	gram	%	ohms mm^2/m
Copper	40	36	15—23	0.0175
Copper-cadmium 0.6%	40	56	5—16	0.0183
Silver	40	70	2—3	0.019
Copper-silver	40	138	1—2	0.022

A special use of thin enamelled copper wire is in the manufacture of insulated stranded wires for high frequency purposes.

These wires, which are divided into a large number of thin units in parallel and insulated from each other, are used especially where solid wires would give too much eddy current loss. Because of the fact that very thin wires, sometimes less than 100 μ in diameter, are used, it is clear that a good space factor can only be attained with the use of enamel as insulator.

Various requirements are made in the braiding of these wire, because for example care must be taken that the same wires do not keep to the outside of the strand over the whole length or a large part of the length. The method of braiding is otherwise noticely dependent on the purpose for which the wire is intended. Stranded wires are manufactured in great variety, from very thin for winding small coils, to very heavy interlaced braids with many hundreds of wires for carrying large currents, for instance in transmitter installations *(fig. 6)*.

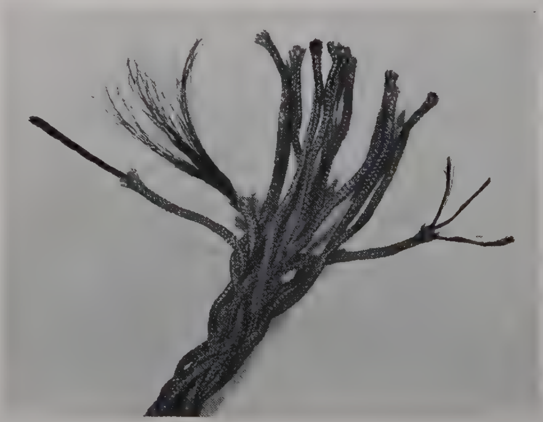

Fig. 6. Heavy stranded wire consisting of 12 bundles braided together. Each bundle is covered with silk and consists of 90 enamelled wires of 0.07 mm core diameter.

In this brief review of enamelled wire in its various forms, the practical applications of the material have not been exhausted. We have confined ourselves to the cases where the enamel forms the only insulation of the wire. Enamelled wire is also employed in combination with the spinning or braiding of paper, cotton, silk or artificial silk about the wire, impregnated or otherwise, or subsequently covered with a layer of lacquer (usually of cellulose derivatives). The discussion of these kinds of wire, however, is outside the scope of this article.

THE COLOUR REPRODUCTION OF INCANDESCENT LAMPS AND "PHILIPHANE GLASS"

by P. J. BOUMA.

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"Philiphane" or "Neophane" glass is a glass which has an absorption band in the yellow region of the spectrum. By using this glass as an envelope for the bulb of an electric lamp, most of the colours, and particularly the blue, are reproduced with greater saturation. The loss of light flux is only slight.

Introduction

As has already been explained in a previous article [1]) the estimation of the quality of colour reproduction of a source of light depends very much upon the purpose for which it is desired to use that source of light.

In some cases it is a question of obtaining light which shall resemble daylight as closely as possible. This ideal may be approached by providing the electric lamp with a blue bulb which makes the spectral distribution of the light more nearly like daylight. Good results may also be obtained with gas discharge tubes in which the line spectrum of a gas is complemented by the continuous spectrum of fluorescent substances.

In many cases however there is no desire at all to imitate daylight, and the requirement is made that the surroundings shall have a pleasant, cosy appearance, that persons shall have a healthy appearance, that certain articles appear fresh and tasteful, etc. We shall concern ourselves here with the question of whether electric light can also be improved in this respect by the introduction of a coloured envelope.

What absorption curves must be considered?

It is clear that large portions of the spectrum must not be weakened to any extent by the bulb. This would cause too great a decrease in the efficiency. Only an improvement of the colour which can be attained with a relatively slight loss of light is to be considered.

The only possibility thus consists of the absorption of one or more relatively small regions of the spectrum. What colours may be considered in this connection?

In general, absorption of a given colour is accompanied by the following two objections:

1) An object which reflects almost exclusively this colour appears too dark.

2) Objects which exhibit the colour under consideration in a less saturated form appear still less saturated.

The first objection holds particulary for the colours at the extremities of the spectrum, thus for red and blue. Very saturated red, for example, can only occur when a material reflects practically exclusively red and orange. The same is true of blue.

For yellow, however, the situation is different. Highly saturated yellow occurs in nature as a rule, not because only a narrow region of the spectrum is reflected, but because red and green as well as yellow are fairly well reflected, and only blue and violet are absorbed to a large extent. Such a phenomenon appears in the case of the yellow "Selectiva" light used for automobile and bicycle lamps. In this case a very saturated yellow colour is obtained by the absorption of the blue and violet only. Strong absorption of the yellow therefore will cause only a relatively slight decrease in brightness of saturated yellows.

The second objection also holds particularly at the extremities of the spectrum: the blue, which is reproduced in electric light in a much less saturated form than in daylight, may certainly not be made still duller. The saturation of the red may also not be decreased too much, since otherwise the reproduction of skin colour would be made worse.

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[1]) Philips techn. Rev. 2, 1, 1937.

For the reasons mentioned above the second objection is also of much less importance in the case of yellow. Moreover the sensitivity of the eye for the observation of differences in saturation is lowest in the yellow 2). It is therefore obvious that the influence exerted by absorption of part of the yellow on the reproduction of colour deserves further study.

The influence of "Philiphane" ("Neophane") glass

Absorption of part of the yellow can be attained by surrounding the lamp with a bulb of the so-called "Philiphane" ("Neophane") glass. The influence of this glass was studied by comparing an incandescent lamp with an ordinary opal glass bulb to one suspended in a bulb of "Philiphane" glass, according to the method described elsewhere in this periodical1). The main feature of this method is that a large number of differently coloured cards are lighted partially with one and partially with the other source of light. *Fig. 1* gives the result of the comparison; the arrows indicate the direction in which the "Philiphane" glass causes the colours to be displaced.

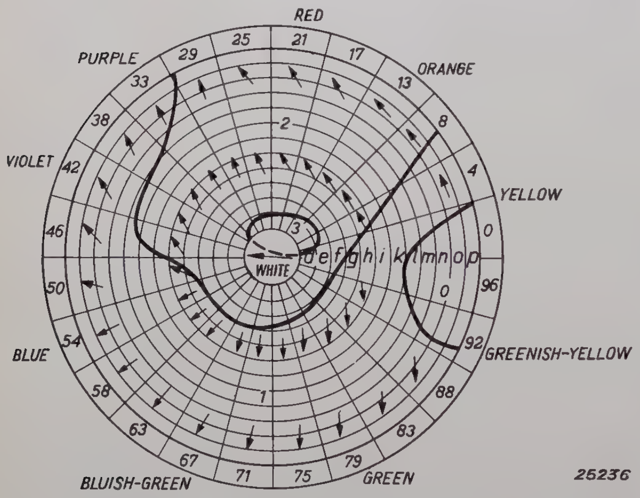

Fig. 1. Comparison of the colour reproduction by an incandescent lamp with and without a bulb of "Philiphane" glass. The arrows indicate the direction of colour change when the lamp is enclosed in a "Philiphane" bulb. The rectangles represent the colour cards of Ostwald's colour atlas. The saturated colours lie toward the outside, the least saturated in the middle.

3: region of poor correspondence
2: region of moderate correspondence
1: region of good correspondence
0: region of perfect correspondence.

For the sake of comparison *fig. 2* shows how the incandescent lamps shift the colours as compared with daylight. In the first place it will be noted that the differences in fig. 1 are in general relatively small. Only with some very unsaturated colours, especially with orange, is the shift so large that we must speak of a totally different colour (region 3).

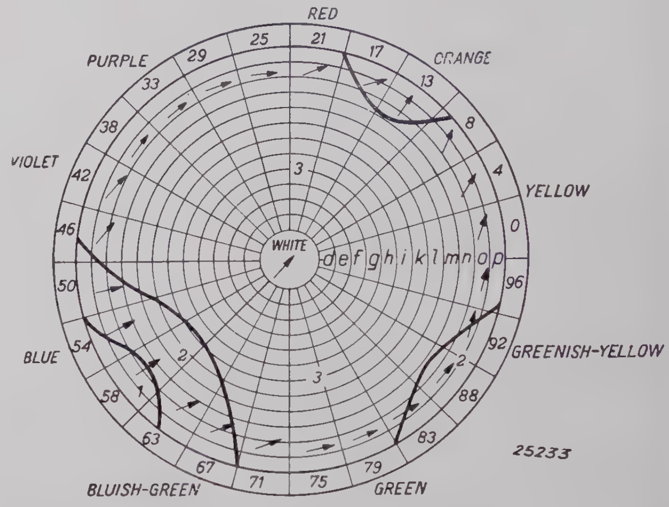

Fig. 2. Comparison of the colour reproduction by an electric lamp and by daylight. The arrows indicate how the colours are shifted upon transition to electric light.

We must therefore pay particular attention to the direction of the displacements occurring at such points. As was to be expected the arrows point in general away from the saturated yellow.

The majority of the colours have become more saturated, a change which is to be desired especially at relatively low levels of illumination. In particular the blue, which upon changing from daylight to incandescent light has become considerably less saturated (fig. 2) is again reproduced in a more saturated form.

The orange is shifted toward the red: the shift in the direction yellow to red is in general experienced as an increased "warmth" of that colour. This shift also gives a more healthy appearance to the complexion.

The green, which upon transition from daylight to incandescent light had become a somewhat dubious yellow-green, goes back to green again under the influence of "Philiphane" glass.

Finally we note that white and the very unsaturated colours are shifted in the direction of blue-violet. This may certainly not be considered an advantage; since however the change is not very great (less than $^1/_3$ of the difference between incandescent light and daylight), and moreover since it lies almost in the same direction as the shift on transition from daylight to incandescent light, it is not very disturbing.

The results found may be summarized as follows.

The use of "Philiphane" glass has the advantage

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2) D. Judd, J. Opt. Soc. Amer. **25**, 24, 1935.

of reproducing most colours in a more saturated form and of making the orange-yellow warmer. Various disadvantages in the use of incandescent light, such as the faded appearance of blue and the shift of green toward yellow-green, are partially overcome. The most important advantages of electric light such as the high saturation of orange and of the colours in its neighbourhood, the greater intensity of red, etc. are retained.

In those cases where the first condition of the illumination is the creation of a pleasant, cosy sphere in which many warm colours occur and in which we ourselves appear especially well, "Philiphane" glass is actually able to give a better reproduction of colour than ordinary incandescent light. This is especially true in the case of its use in hotels and restaurants, for illumination of certain show windows such as those of provision shops and florists etc.

A special warning must be given against considering the use of "Philiphane" glass as an attempt to imitate daylight. For this purpose quite other methods must be used.

The improvement in colour is of course accompanied by an inevitable loss in light intensity. In the case of "Philiphane" glass this loss is about 20 percent. If it is desired to increase the colour effect by the use of thicker or more deeply coloured glass, the loss of light will also increase.

We must add a few words about the ratio of the brightness of the colours with and without "Philiphane" glass.

For several of the colour cards with fairly saturated colours used in the above described comparison the point is determined in the colour triangle upon illumination with each of the two kinds of light, under the simplified assumption that Neophane glass absorbs completely the radiation from 570—600 mμ. The shifts were entirely in the directions already found in fig. 1. From the same calculation we found the coefficients of reflection for both cases. These are tabulated in *table I.*

Table I.

No.	Colour	Coefficient of reflection	
		ordinary	"Philiphane"
	Ideal white	100	100
nc 25	red	36	32
nc 17	orange	40	34
nc 4	yellow	57	55
nc 83	green	23	25^5
nc 58	blue	17	19
nc 42	violet	17	17
nc 33	purple	31	29

We see that no very great differences appear. There can therefore be no question of the "disappearance" of any colours. It is true that the differences can become somewhat greater with very saturated colours, but on the other hand "Philiphane" glass always continues to transmit a part of the yellow. In this respect therefore we need not fear unpleasant surprises.

Finally we note that "Philiphane" glass may have other practical applications besides its use in envelopes for electric lamps. The advantages offered by the use of this glass can be of two sorts:

1) The glass offers the possibility of removing an unpleasant excess of yellow from a mixture of several kinds of light. Especially in combination with mercury lamps such cases may occur.
2) As may be seen immediately from fig. 1, "Philiphane" glass displaces the red and green in opposite directions, so that the difference between these colours becomes more pronounced. The use of spectacles of "Philiphane" glass by persons with a poor sense of colour might be able to make easier the distinction of coloured traffic signals.

APPLICATIONS OF CATHODE RAY TUBES I

by H. VAN SUCHTELEN.

621.317.755 : 621.385.882

An early use of cathode ray tubes was in the study of alternating electric potentials. In comparison with mechanical oscillographs, such as the loop oscillograph, the cathode ray tube has the advantage that the beam of electrons has practically no inertia, and that therefore very high frequencies and phenomena of very short duration can be made visible. The rising technique of radio communication immediately seized upon the cathode ray tube as a welcome instrument of investigation. Due to the presence of two sets of deflection plates the beam of electrons can be deflected in two mutually perpendicular directions; this offers the possibility of examining the behaviour of a voltage as a function of the time in a very simple way, or of examining the relation between two voltages. In the first case the set of plates for horizontal deflection obtains its voltage from a "linear time-base", that is, a potential which increases linearly with the time for the whole period, and then falls back to its initial value again. In the second case one of the two voltages is applied to each set of deflection plates. If for instance the two alternating voltages are sinusoidal with an integral ratio between their frequencies, so-called Lissajous figures result.

The voltage necessary to obtain good deflection of the beam is about 20 to 60 volts, the load on the source of potential is then nearly zero, since a capacity of a few $\mu\mu$F only is present as loading impedance between the deflection plates. It is obvious that this will sometimes be an important advantage, especially in working with high frequencies.

One very good feature of the newer cathode ray tubes is the fact that the fluorescence image on the screen is sufficiently brilliant to be observed in fairly light surroundings, thanks to its great brilliancy, so that photography is unnecessary unless it is desired to record a particular result. The direct observation of the fluorescence image is obviously of great advantage, since, as in the investigation of particular circuits, the result of changes in the circuit may be seen immediately on the screen of the cathode ray tube.

The technical development of cathode ray oscillographs has taken these possibilities into consideration. In addition to large permanent set-ups of oscillographs with complete photographic equipment, more and more small portable equipments have recently come into use. In these smaller sets the cathode ray tube with its power supply, amplifier and time-base generator and synchroniser is built as a compact unit [1]), so that it becomes very simple to transport the oscillograph to the place where the phenomenon to be investigated is taking place. This is one of the factors which have led to the more general use of the cathode ray tube as a measuring instrument in the investigation of innumerable phenomena. In a series of short articles we shall discuss some of the applications. The articles will be illustrated by photographs of the oscillograms [2]) which may be observed on the screen of the cathode ray tube.

Oscillograms of power mains

The most obvious oscillograms of alternating currents or voltages are the curves recorded for power mains. The oscillograms of *figs. 1* and *2* offer little that is new to the electrical engineer. Upon careful consideration it will be seen that the curve of fig. 1 is slightly more angular than that of fig. 2. Such differences may be of influence on the calibration of voltmeters or wattmeters. Although the two curves in this case were obtained from two different mains, the same mains can also give different curves according to the nature of the load. It is sometimes important to know whether or not a given load on the mains, added to the circuit at a point far from the power station, will cause a distortion of the voltage curve, and to know the extent of such deformation. In such cases a convenient portable oscillograph offers great practical advantages. A rapid demonstration on the spot in the form of an oscillogram can obviate long discussions.

Although upon comparison of fig. 1 and 2 the latter appears the least deformed, it is not permissible to conclude immediately that the latter source of voltage will in every case give less departure from normal behaviour. If the voltage to be investigated is not connected directly but through a simple RC circuit (*fig. 3*) with the cathode ray oscillograph, the main frequency may be very much suppressed with respect to harmonics of much higher order. Afterwards these harmonics which have been filtered out may be amplified until they give a clearly visible amplitude on the cathode ray tube. In this way a new oscillogram (*fig. 4*) is obtained with the voltage of fig. 2. In fig. 4 fine indentations may clearly be seen which indicate a frequency very much higher than the 50 cycles of the mains. Such a ripple, which may be caused by the slots in the rotor of the alternating current generator, was found to present difficulties in the initial development of radio valves heated with alternating current. An oscillogram like that in fig. 4 gives a decisive answer to the question as to the cause of the interference tone heard. At the same time it may be concluded from the evidence which the oscillogram presents that the interferences, due to their high frequency, could be suppressed by connecting a fairly simple filter into the mains circuit. This was actually found to be the case.

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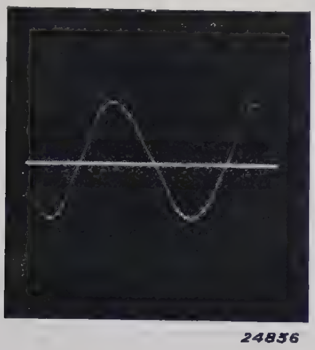
[1]) Such an apparatus was described fully in Philips techn. Rev. **1**, 147, 1936. The cathode ray tube of the type DG 9-3 with a screen diameter of 9 cm is used. The following oscillograms were recorded with this apparatus.

[2]) The photographic recording of oscillograms is usually very simple. The photographs in this article were made with a very simple box camera and an extra lens; time of exposure about $^1/_2$ sec.

1



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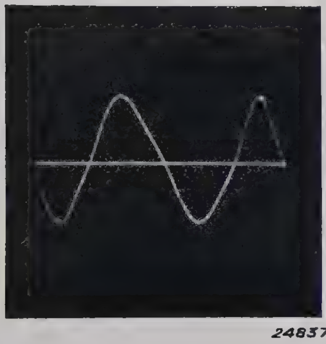

Fig. 1 and 2. Oscillograms of the voltage of two different 50 cycle power mains. The first mains voltage appears to have slightly more deformation.

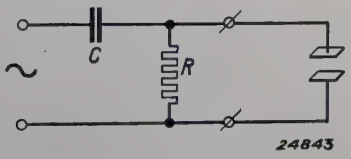

Fig. 3. A simple filter is connected between the mains and the deflection plates of the cathode ray tube in order to decrease the intensity of the fundamental frequency of the alternating voltage between the plates.

It will have been noticed that the general character of the curve in fig. 4 differs very much from that of figs. 1 and 2. The horizontal deflection is in this case not obtained from a linear time-base, but from the 50 cycle alternating voltage of the mains. Since the filter does not completely suppress the fundamental frequency, an alternating voltage of 50 c/s is also present on the other set of deflection plates. The frequency of the latter is shifted in phase with respect to the mains voltage, and thus gives rise to the elliptical figure. This device is used in this case in order to make sure immediately without careful adjustment that the time-base is accurately synchronized with the mains voltage. This is important for the purpose of deciding whether the fine indentations have their source in the mains themselves or are due to an external source of interference. In the latter case the ripple will never be completely stationary, but will run more or less rapidly along the ellipse.

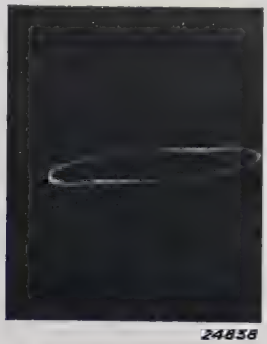

Fig. 4. The oscillogram of the mains of fig. 2 recorded with the use of the filter of fig. 3. The horizontal deflection is obtained from the mains voltage and not from a linear time-base. With a vertical deflection obtained by means of a sinusoidal alternating voltage of 50 cycles, an ellipse will generally be formed The fine indentations of the approximately elliptical line indicate disturbances which may, for example, have their source in the slots of the rotor of the alternating current generator.

Finally a practical example will show how quickly it is possible to work with the cathode ray oscillograph. As was mentioned, an *RC* filter was necessary to obtain the curve of fig. 4. The resist-

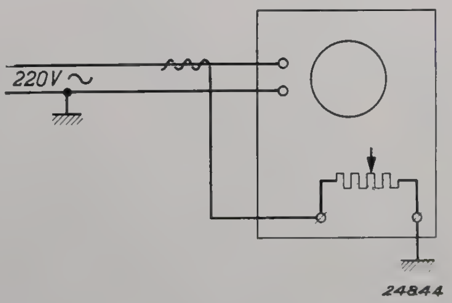

Fig. 5. Practical construction of the filter circuit represented in fig. 3.

ance was here formed by the input potentiometer of the built-in amplifier, while the capacity was formed by winding an insulated wire connected to the input terminal of the amplifier several times loosely around the unearthed power mains cable (*fig. 5*).

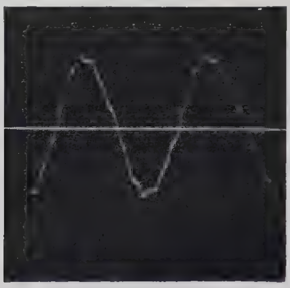
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Fig. 6. Oscillogram of "standard mains" which are used in laboratory to test radio receivers.

Phenomena such as that illustrated by fig. 4 led to the construction of "standard mains" with an artificial interference by overtones. In the Philips Laboratory such mains of 50 c/s with 3 per cent overtones of 500 cycles are used for testing radio receivers. The oscillogram of these mains is given in *fig. 6*.

The oscillograms of direct current mains also may sometimes be important. When the mains are not fed from an accumulator battery a ripple will usually be observed superposed on the straight line which represents the direct voltage. *Figs. 7, 8* and *9* give examples of what may be encountered in practice. Fig. 7 is the oscillogram of 130 volt mains from a source of 40 kW, used in connection with various small motors. The ripple, which is due in general to the dynamo, can scarcely be distinguished. At night, instead of the 40 kW dynamo, a 6 phase rectifier of lower power is used. This makes no difference to the running of the machines connected with the mains. On the oscillogram, however, the successive crests of the sine curves of the six alternating current phases can be very clearly distinguished. The short oscillation of much higher frequency at the end of each crest is typical. It is from such an oscillation that interference may be expected. We shall return in a following article to give an example of this.

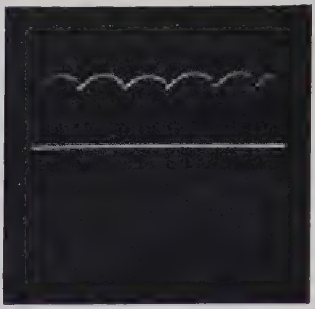
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Fig. 8. Voltage of direct current mains fed by a 6 phase rectifier. The voltage exhibits a pronounced ripple, formed by the crests of six sine curves. In addition, at the end of each section of sine curve an oscillation of much higher frequency may be seen.

A third example of direct current mains is the oscillogram in *fig. 9* of a 5 kW motor generator. With this smaller machine the ripple is much larger than in the cases of the more powerful machine.

If it is desired to examine the ripple of direct current mains in more detail, the same device may be employed as that with which fig. 4 was obtained, but in this case of course using a normal linear time-base.

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Fig. 7. Voltage of direct current mains fed by a 40 kW dynamo.

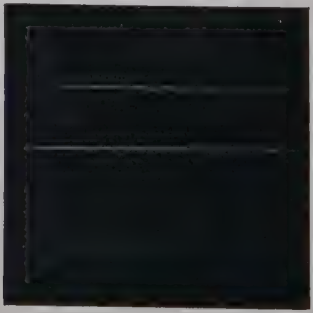
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Fig. 9. Voltage of direct current mains fed by a 5 kW dynamo. Smaller machines often have a much larger ripple than larger machines (fig. 7).

WORK-BENCH ILLUMINATION

by N. A. HALBERTSMA.

628.976

Fine assembly work demands a very intense illumination of the work shop. Because of the fact that the sensitivity to glare increases very much with the level of brightness, the illumination must in addition be very uniform. In this article the points of view are discussed which determine the design of fixtures for an illumination of about 100 ft. candles on the working surface. General as well as local illumination is discussed. The examples give the development of the illumination of an assembly bench for the making of radio receiver valves.

The illumination of the work-bench and the machine-tool where fine work is done has passed through a remarkable development in the last 25 years.

Local illumination, upon which one had to rely out of considerations of economy in the time of the carbon lamp and relatively high prices for current, was gradually displaced by general illumination when, with the large metal filament lamps (especially the gasfilled lamp), light sources with a much higher efficiency and units with a considerable luminous flux became available.

With increasing insight into the value of good and strong illumination for the rapid and accurate carrying out of fine work, there is now a tendency to revert to local illumination without neglecting general illumination.

For the correct evaluation of the two very different methods of illumination it is important to find out what objections there are to general illumination when it is desired to raise the illumination to high levels (around 100 ft-candles and higher), and to what extent these objections can be met by local illumination.

We have in mind operations which make greater demands on the eye than writing or reading (for which purposes general illumination of sufficient intensity can be easily obtained).

These are many such fine operations. It is well known that drawing makes greater demands than writing. Fine lines and the slightness of contrast in the case of lines drawn with a hard pencil or in tracing etc. require many times the light intensity with which one can write comfortably.

At the work-bench and on the machine-tool the small dimensions of the details to be observed or the slight contrasts create a demand for a strong illumination.

In a report of the English "Industrial Health Research Board" and the "Illumination Research Committee" [1]) Weston arrived at the following table of illumination required with decreasing size of details to be distinguished:

Table I.

Visual angle of the details to be distinguished	Dimensions at a distance of 14 inches	Required illumination
10′	1 mm	1.6 ft. candles
8′	0.8 „	1.8 „
6′	0.6 „	2.4 „
5′	0.5 „	3.2 „
4′	0.4 „	5.4 „
3′	0.3 „	24.0 „
2′	0.2 „	80.0 „
1′	0.1 „	160.0 „

As test object Weston used cards with Landolt rings of the type shown in *fig. 1*. The test person had to mark the rings whose slit was in one of the eight positions given. As a measure of the performance of the eye Weston took the number of rings marked in a given time. The number generally increases in such tests with the size of the rings on the card and the intensity of the illumination. There is, however, a limit to the speed of observation, even although the light intensity is increased to that which occurs in the summer in full sunlight (about 10 000 ft. candles). The "required illumination" according to the above table is the illumination at which this limit has been reached within 2 per cent. If it is desired to pass this limit, spectacles or a magnifying glass must be used [2]) in addition to strong illumination.

In the table is the width of the slit, it may be noted, that the slits as printed in fig. 1 subtend a visual angle of about 3′ at normal reading distance. To give some idea of this angle, it may be noted that the angle is also about 3′ for the details of the type of this periodical at a normal reading distance.

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[1]) H. C. Weston. The relation between illumination and industrial efficiency I. The Effect of Size of Work, London, His Majesty's Stationery Office, 1935.

[2]) The magnifying glass of the watchmaker and engraver is the best known example of this, but H. C. Weston and A. Adams state in Report No. 40 of the Industrial Fatigue Research Board, London 1927, that operators of knitting machines with normal eyes needed spectacles of + 1,5 D when they had to transfer the stitches of the stocking to needles on the knitting machine of which there were 20 to 22 per inch and whose separation therefore was slightly more than 1 mm.

In Weston's tests the contrast was as great as possible (black and white). Lower contrasts require greater intensity of illumination.

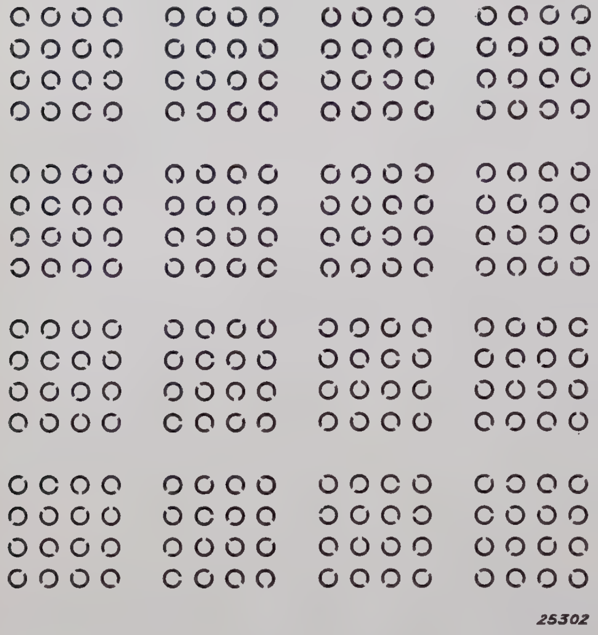

Fig. 1. Test card for the determination of speed of observation. The visual angle of the details to be distinguished is 3′.

The curve of the sensitivity of the eye to contrast as recorded by König-Nutting (*fig. 2*) shows that contrasts with ratios of brightness of 1 : 1.02 ($H/\Delta H = 50$) at a brightness of 1 cld/sq. ft., that is at intensities of illumination of 300 lux on a surface with 10 per cent reflective power, are no longer observed.

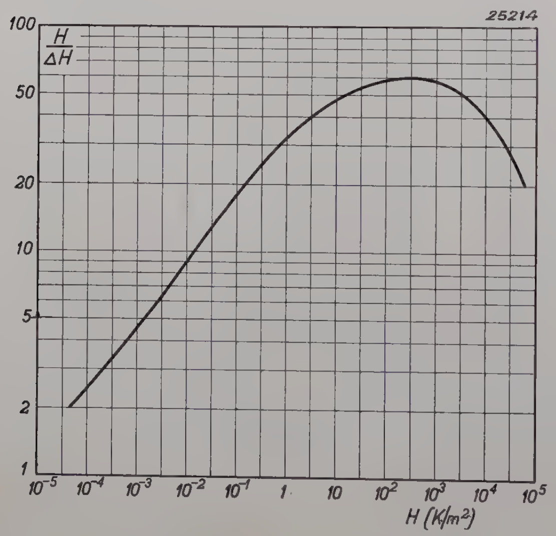

Fig. 2. The smallest observable contrast in brightness $H/\Delta H$ as a function of the brightness. H is the lowest of the two brightnesses, ΔH the difference in brightness. The ratio of brightness is therefore $1 + \Delta H/H$.

The high standard of accuracy which is now often required to ensure interchangeability of parts, has in many factories necessitated high intensities of illumination (100 ft. candles for example) at the work-bench.

Objections to very intense general illumination

The following difficulties are encountered with very intense general illumination:

a) The operating costs and the heat development increase proportionally with the power installed and become important at 10 W/sq. ft. and higher. The development of heat can become disturbing not only because of the heating of the air, but also due to the radiant heat (the use of the mercury vapour lamps e.g. decreases the heat developed at equal intensities of illumination by about one half).

b) In rooms of moderate height (12 to 14 ft.) the brightness of the fixtures quickly becomes disturbing when the intensity of illumination is increased to a large degree. Ward Harrison [3]) pointed out that two phenomena must be kept in mind in designing installations with high intensities of illumination. The first is that the contrast in brightness, between the lightest and the darkest parts of the field of vision, which is permissible in connection with the risk of glare, decreases with increasing of brightness of the field of vision. This fact was discovered by Nutting [4]). With tenfold increase of brightness of the field, the maximum brightness may only be doubled if the size of the source of light remains the same. In the second place account must be taken of the fact that increase in size of the brightest parts of the field of vision (the lighting units, which in this case were diffusing globes) decreases the maximum permissible brightness. This practically means that no use can be made of the above-mentioned doubling, and that one is limited to a maximum brightness. Therefore with increasing light flux from the light sources the apparent surface of the diffusers must in fact increase in the same ratio. With reflectors, and with indirect illumination this must be kept in mind. Entirely apart from economic considerations, increase in the number of light points, for instance to 1 per 20 sq. ft., provides no solution of the difficulty met in a radical increase of the level of illumination (up to 100 ft. candles for example).

c) In long factory rooms the workmen are distracted by the glare of the large number of fixtures or the strongly lighted ceiling where the brightness is a multiple of the brightness of the working surface toward which his eye is directed.

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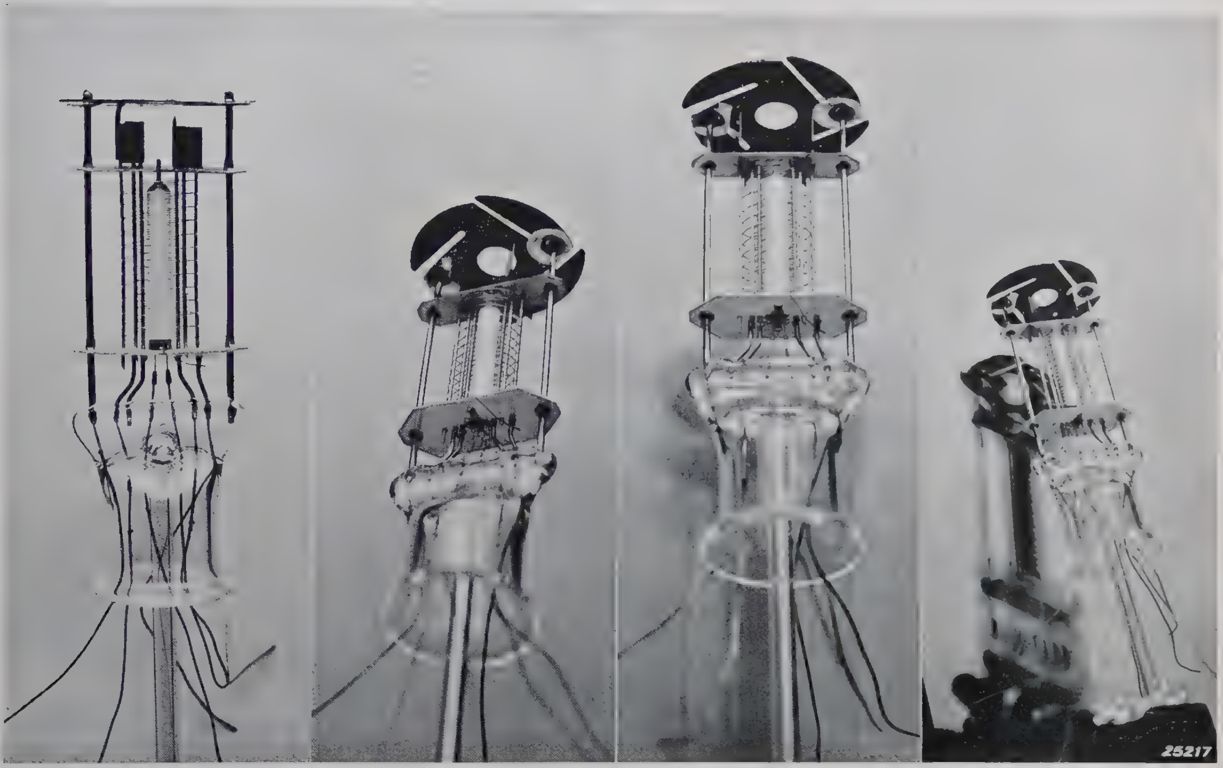
[3]) W. Harrison. What is wrong with our 50 ft candle installations? Trans. Ill. Eng. Soc. **32**, 209, 1937.

[4]) P. G. Nutting, Trans. Ill. Eng. Soc. **11**, 943, 1916.

d) In the presence of a large number of closely spaced lighting points the intensity of the shadows will as a rule be small, but on the other hand, with pieces of work made of shiny material, there is an increase in the number and intensity of the bright spots caused by specular reflection.



a) b) c) d

Fig. 3. The inside of a pentode, photographed under various systems of local illumination.
a) and b): Large enamelled reflector with lamp shielded from below. Different positions of the piece of work. The supporting wires may, according to their position, appear bright or dark against the background, but exhibit no disturbing light reflexions.
c): Lamp, with inside frosted bulb, not shielded from below. Disturbing light reflexions appear.
d): Lamp with clear glass bulb and a very small reflector. The reflexions become stronger. In addition a disturbing shadow appears.

Characteristics of strong local illumination

We shall now try to see to what extent the above-mentioned objections to strong general illumination can be met by strong local illumination.

a) The heating of the air is less, because even if one assumes 10 sq. ft of work-bench space per man, and installs 100 W for that space, the number of work-bench places in a room still remains so much smaller than the total floor space in sq. ft that the heating of the air will be much less owing to the smaller current consumption.

As lighting unit a reflector only can be used, the eyes of the worker not supporting a diffusing bulb in the immediate neighbourhood. The proximity of the lighting unit to the head of the worker, however, makes it necessary to make special provisions against radiant heat. Neither the hands nor the head of the worker should feel the presence of heat radiation. If the reflector becomes very hot, it also becomes a source of radiant heat. Generous dimensions and good ventilation for removing the warm air which collects in the reflector will keep the temperature of the reflector low.

b) A reflector for local illumination which is so formed and so placed that the worker sees neither the lamp nor any part of the strongly lighted inner surface of the reflector [5]) will not be blinding by itself. On the other hand very disturbing light reflexions will appear on a piece of work made of polished material. These reflexions are caused by the lamp as well as by polished parts of the inner surface of the reflector. The brightness of an inside frosted lamp of 75 W is of the order of 150 cdl/sq. inch. Under this lamp metal objects will show reflexes of about 60—120 cdl/sq. inch, enamelled or lacquered objects (with a direct reflection power of 4 per cent only 6 cdl/sq. inch). If, however, the lamp is shielded from below, there will still be reflexions of the lamp in an enamelled reflector of 6 cdl/sq. inch which cause reflexions of 3 cdl/sq. inch in metal objects.

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[5]) When a small portion of the inner surface of the reflector remains visible, this cause of dazzle may be removed by painting that part dull black.

c). Since the fixtures for local illumination are at about eye-level, it is also important for the other workers in the hall not to be able to look into the reflector. Otherwise the objection to general illumination mentioned under c) above would hold equally and perhaps still more for local illumination.

d). Shadow formation may be of great importance according to the mixture of the work to be done. Sometimes it is desirable, in other cases every attempt is made to avoid it. While in the case of general illumination we have long been aware of the influence of the system of illumination, direct, half indirect or indirect, on the formation of shadows on the piece of work, it has only recently been realised that local illumination can also be adapted to the requirements of shadow formation. Reflectors with small diameters which used to be used exclusively for local illumination will always produce strong shadows. With increasing diameter of the reflector the shadows become less pronounced because the light coming from a reflector with a diameter of 12 or 15 inches subtends a fairly wide solid angle because of the short distance between reflector and work. At a distance of 13 inches this solid angle is approximately equal to the solid angle of the incident light in indirect lighting where a surface of about 7 ft diameter on a ceiling 12 ft high radiates the light.

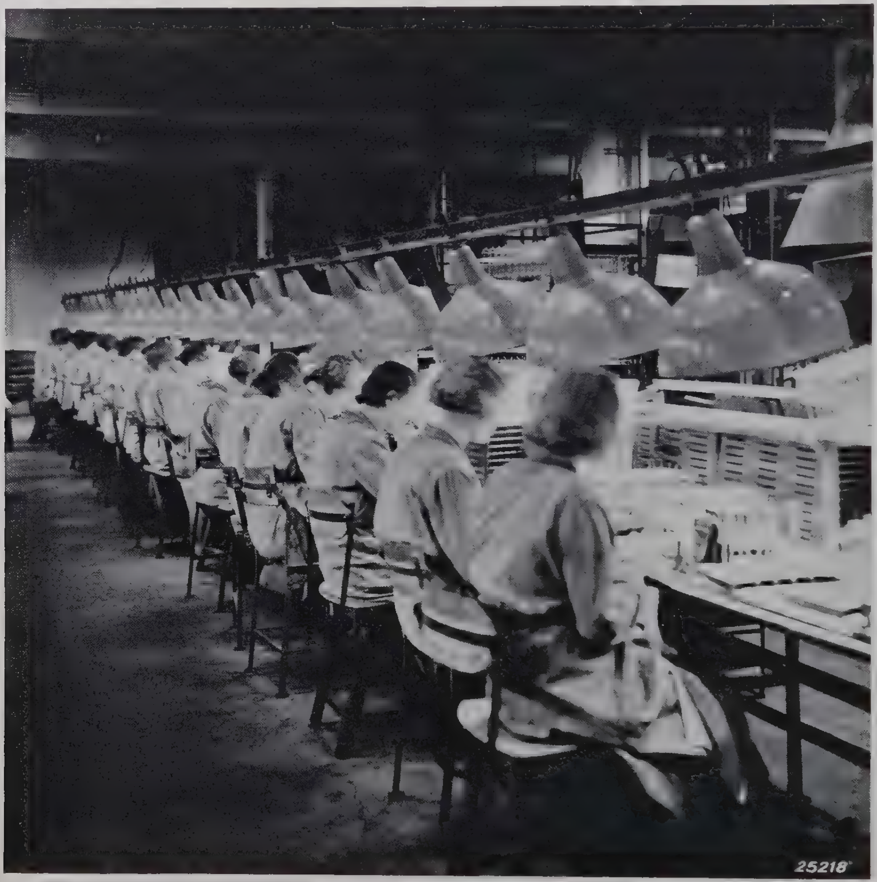

Fig. 4. Work-bench in an assembly department with the illumination whose results are shown in figs. 3a) and b).

The lighting of an assembly bench.

The ideas on local illumination of high intensity (about 100 ft. candles) summarized in the foregoing have led to a special lighting installation on the work benches in the radio valve department of the Philips Incandescent Lamp Works, where in 1934 repeated complaints of eye troubles occured with persons who were employed in the assembly of radio valves.

This assembly work must be considered as the limit of performance of the eye, since in addition to the handling and selecting of often very fine parts, the eyes are not focussed on a single plane surface only, as in the work of a watchmaker, but they must be focussed at different distances in space.

The modern radio valve contains a number of concentric grids which are born by supporting wires insulated from each other. Helices of fine wire are used as grids.

These bare metal wires can be observed in two ways. They can appear dark against a light background and thus be seen as silhouettes, when the source of light is not reflected in the direction of the eye by the bright metal (see *fig. 3a*), or they may appear bright in contrast to the background when they reflect the light.

Whether or not the reflection is observed by the eye depends upon the position of the work. The same supporting wires, in the position shown in *fig. 3b* are lighter than the background due to reflection of the light source.

In order to prevent the reflexion in the metal parts and also in the glass from becoming too strong and causing dazzle, and in that way making observation in the immediate neighbourhood more difficult, the surface brightness of the light source must not be too great. The lamp is therefore shielded from below in the reflector. The surface brightness is then of the order of magnitude of 3 cdl/sq. inch at the most, if the reflector is dull white on the inside. If the enamel of the reflector has a shiny surface, reflexions of greater brightness about 30 cdl/sq. inch, occur, and the brightness of the metal wires in certain positions also becomes greater.

The importance of the shielding of the lamp may be seen from a comparison of the illuminations obtained with shielding (figs. 3a and b) and the illuminations obtained without shielding (figs 3c and d).

The omission of shielding has two results when a lamp of normal type, matted on the inside, is used:

1) The light reflexions on the metal wires and in the glass become much stronger (see fig. 3c).
2) Heavy shadows occur.

Both phenomena become more pronounced if a clear glass lamp and a very small reflector are used. In fig. 3d) the strong reflexions and heavy shadow may be seen.

The impressions given by these photographs have been confirmed by tests on a large scale.

With an illumination as that used in figs 3a and b the production per hour was highest and the number of mistakes smallest. The number of complaints of eye trouble also decreased considerably.

Considering the nature of the work and the great demands which it makes on the eye, a careful selection of personnel by means of a thorough eye examination is to be desired.

The enamelled reflector, matted on the inside (*fig. 5*) and 15 inch in diameter is fastened 15 inch above the work-bench in a slanting position. The source of light is a lamp of 75 Watt with a clear glass bulb.

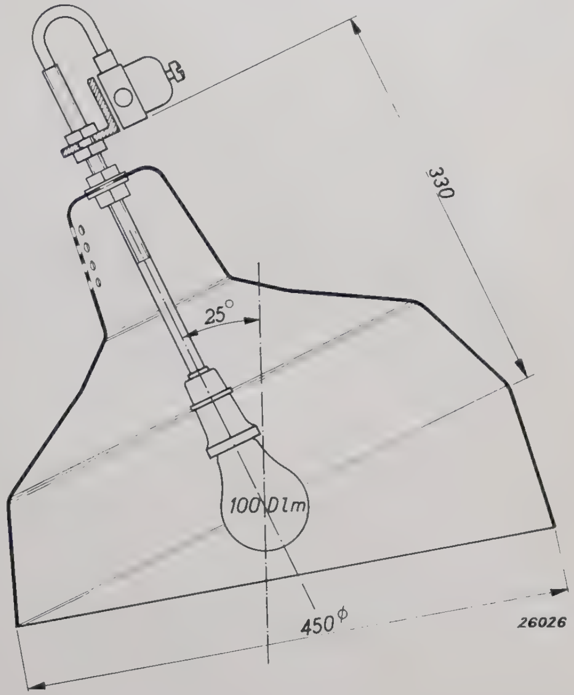

Fig. 5. Sketch of the enamelled reflector for the work-bench illumination of figs. 3a and b.

Directly under the lamp on the work-bench there is an illumination of about 55 ft. candles. As a rule the work is held at some distance above the bench. At this point a light orange-coloured, matt-finished, metal plane is placed at an angle of 75 ° with the horizontal. This serves as background for the work to be inspected.

When the work is held before this plane, the horizontal intensity of the illumination is about 80 ft. candles, and the light falls from the wide opening of the reflector on the work from all sides and through the various wires in such a way that the parts in the interior of the piece of work can also be seen without hindrance from shadows. The large surface of the reflector and the ventilation holes in its neck prevent it from becoming hot, and thus prevent disturbing heat radiation on the head of the worker.

Transmitter building (middle) with cooling tower (left) of a 20 kW Philips medium wave broadcasttransmitter at Rio de Janeiro.

In the background can be seen part of a self-radiating aerial tower belonging to this station.

A ROTATING DIRECTIONAL AERIAL FOR SHORT WAVE BROADCASTING

by P. J. H. A. NORDLOHNE.

621.396.677.029.58

A description is given of the rotating directional aerial erected at Huizen for broadcasting from the transmitter PCJ on 31.28 m.

On November 16th 1937 a rotating directional aerial was put into use at Huizen for experimental transmission by the short wave station PCJ described in the previous number, with a frequency of 9.59 megacycles (wave length 31.28 m). This directional aerial was designed for a power of about 75 kW carrier wave energy.

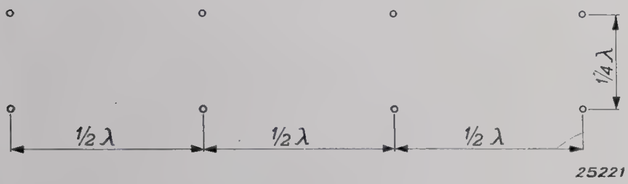

Fig. 1. View from above of a uni-directional aerial.

The purpose of building a rotating aerial was to make possible the restriction of the energy to any chosen direction with a single aerial installation, and in this way to concentrate all the available energy toward a given part of the world, for example toward a given part of North, Central or South America.

Instead of a rotating aerial, up to now it has been usual to build a number of permanent fixed directional aerials for this purpose, each of which served for a single definite direction. The angle of emergence of the beam sent out by a directional aerial can be chosen more or less wide. If aerials with small angles of emergence are built, a narrower section of the earth's surface is reached, but with greater intensity; if, on the other hand, the aerials have large angles of emergence a wider section of the earth's surface is covered, but at the cost of intensity.

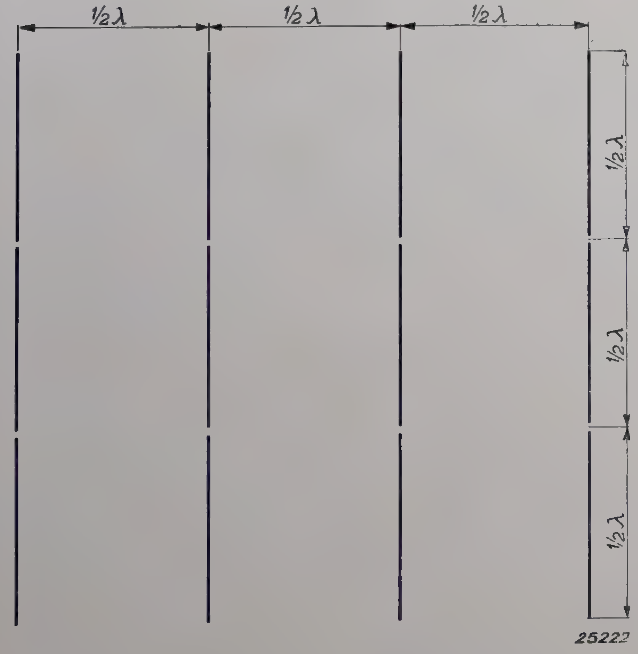

Fig. 2. Position of the half wave aerial wires in the vertical plane.

Considering the fact that the wave length with which one serves a certain distant part of the world is almost always less suitable for another distant part of the world in the opposite direction, since, for example, the state of ionization along the path to the latter is different, it is advantageous to make the directional effect of the aerial one-sided. Thus the aerial must not radiate any energy in a backwards direction. This uni-directional action can be attained by grouping the various aerial wires in two parallel planes which lie at a distance of a quarter wave length from each other, and by giving the currents in front and rear planes a phase difference of 90°.

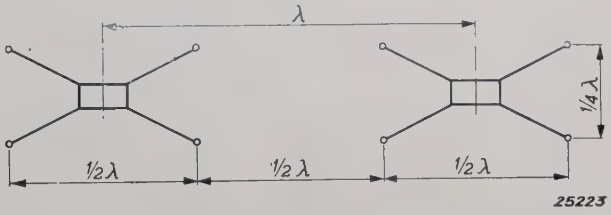

Fig. 3. View from above of the towers with the aerial wires hung on the projecting supports.

Fig. 1 gives a view of the uni-directional aerial from above. The supply is such that the currents in the aerial wires of the front plane are 90° in phase behind those of the wires of the rear plane, so that the waves which the two planes radiate, when they have the same amplitude, will reinforce each other toward the front and exactly neutralize each other toward the back.

The sharpness of the beam depends upon the number of aerial wires next to each other in each plane and on the mutual separation of the wires. If directional aerials for a given frequency are available, the intensity of which falls to one half at 13° on either side of the main direction, and if it is desired to reach all parts of the world from East Africa to and including the United States with an intensity which is never less than half of that in the main direction of the aerial, eight such aerials would be necessary. These directional aerials should be placed along the sides of a polygon to prevent one aerial from exerting too much influence on the radiation diagram of another. The transmitter building may be situated at the centre of the circumscribed circle of the polygon. With this method very large areas of ground are necessary, as well as one or more complicated and expensive switching arrangements.

These objections are avoided with the rotating aerial.

For the rotating aerial of PCJ for a wave length of 31.28 m two 60 m wooden towers were built which can rotate together around a central pivot. In connection with the desired concentration of radiant energy in a horizontal as well as in vertical plane, four aerial wires a half wave in length were suspended next to each other, and three were suspended one above the other in the same vertical plane (*fig. 2*), while two of such planes were placed one behind the other as shown in fig. 1. These aerial wires may be hung in the usual way between the two towers, but in that case the diameter of the circle described by the rotating towers is relatively large. When steel masts are used, moreover, in order to limit the currents induced in them, which would have an undesirable influence on the radiation pattern, the distance from the aerials to the poles would have to be made equal to at least about one wave length, so that the structure would be unreasonably large. The diameter of the circle described can be considerably decreased by using wooden towers and by not suspending the aerials between them, but on the towers themselves. In this case the towers must be provided with projecting supports in the form of platforms (*fig. 3*). Each tower then carries four vertical wires, each of which is divided by two insulators into three half wave aerials whose currents are in phase with each other. Since the distance between the aerials in the front as well as the rear plane is fixed at a half wave length, the distance between the centres of the towers becomes exactly one wave length.

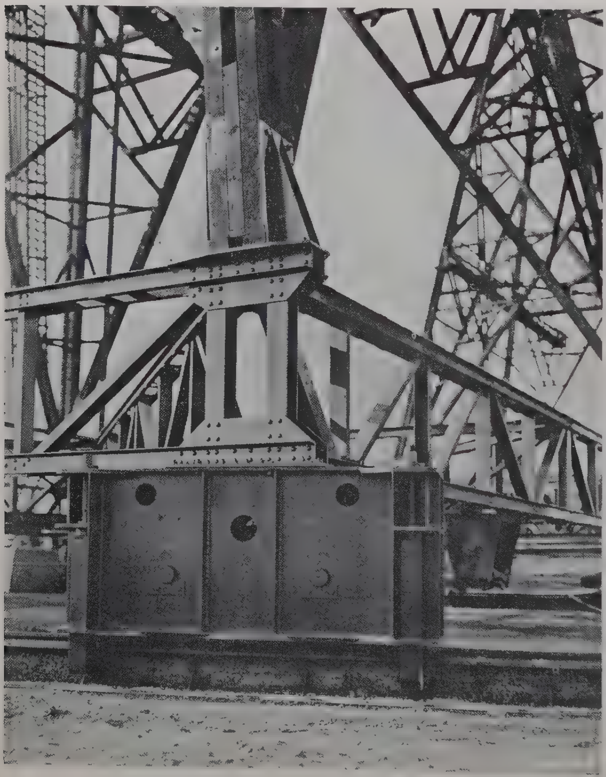
Fig. 4. Wheel boxes on the outer track.

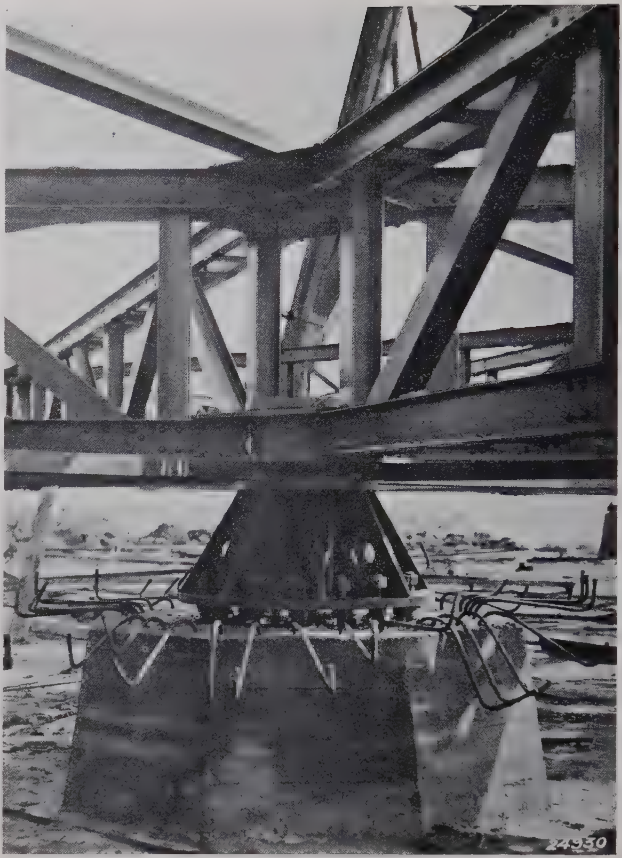

Fig. 5. Anchorage of the steel pivot about which the whole rotating aerial is centred.

In order to allow the whole structure to rotate easily, the two towers must be joined together at their bases. They must therefore be mounted in the same rotating undercarriage. The latter consists of a steel construction about 54 by 13 m which rests at each of the eight points where it bears the towers on a set of wheels (*fig. 4*) consisting of two wheels in a line (16 wheels in all). Four of these sets of wheels are on the outer track, the other four on the inner track. The outer track has a diameter of about 46.4 m and consists of a normal rail AH no. 1, welded to an I-girder, DIN 24, which in turn is anchored in a (circular) wall of reinforced concrete. The inner track is constructed in exactly the same way but has a diameter of about 22.4 m.

Since during rotation in a strong wind the wheels might be pressed against the sides of the rails, the whole structure is centred about a steel pivot which is anchored in a block of reinforced concrete with a heavy base (*fig. 5*). This pivot therefore serves exclusively to take up the horizontal forces.

The wooden towers are made of Norwegian fir impregnated with a substance to prevent rot. The general construction can be seen clearly in *fig. 6*. All joints are made with nuts and bolts, while several important points are provided with iron butt straps. Each wooden tower weighs 18 tons, the steel framework weighs about 40 tons, while each set of wheels weighs 1.5 tons.

The wheels rotate on double ball bearings. There is one set of wheels under each of the four posts of the two towers.

The heaviest load occurs as the result of a wind diagonally against the towers. There is then a 38 ton compressive stress on one side and a 38 ton tensile stress on the other side. In this way a maximum load of 51 tons may occur on one set of wheels: 4.5 tons from the wooden tower, 7 tons from the steel undercarriage, 1.5 tons from the wheels themselves and 38 tons due to the force of the wind. In the construction of the towers the calculations were made, according to the Netherlands Normalization Committee, with a wind force of 70 kg/m² for the first 20 m of height, while for every additional meter of height an increase of pressure of 1.5 kg/m² is calculated. This increase, however, goes only to a height of 40 m, so that above

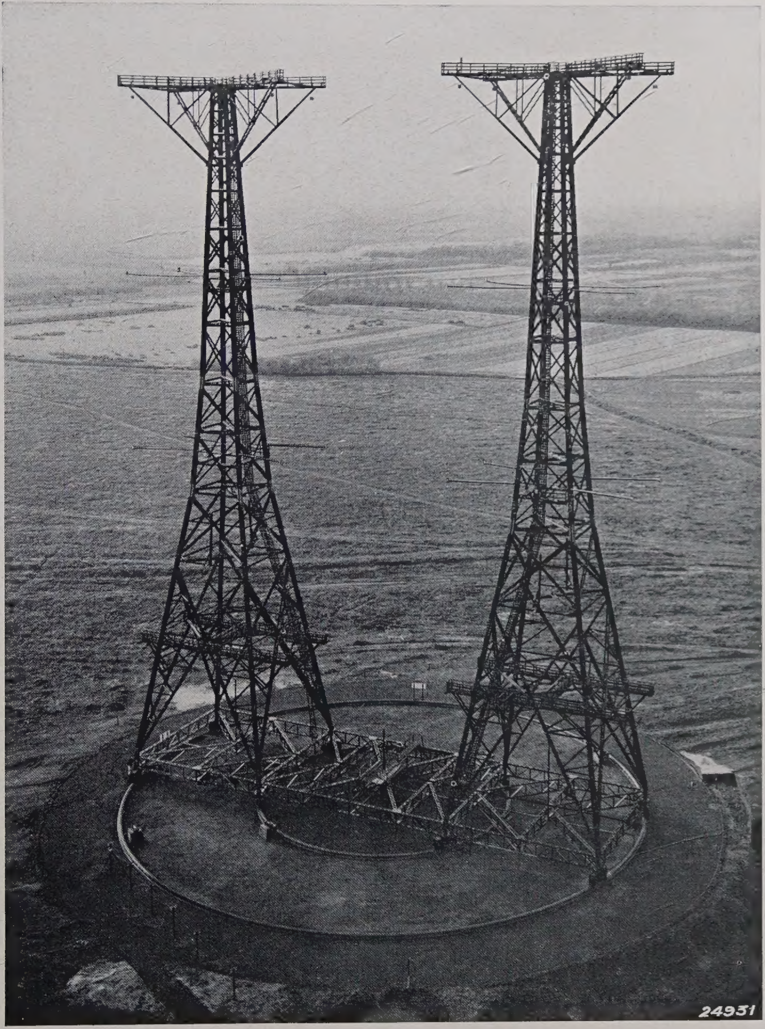

Fig. 6. The wooden towers of the rotating aerial.

this height the pressure remains 100 kg/m². The wind pressure makes heavy demands on the wood construction, considering the fact that the surface on which the wind exerts its force is much greater than that of an iron tower, which can always be constructed in a more slender form. Moreover, the platforms in the shape of a cross, on whose extremities the aerial wires are hung, represent loads which are effective at the top, and thus make large contributions to the moment of the forces acting on the tower.

The construction of a tower was carried out in the following way. Two sides about 20 m high were first built on the ground. After these had been erected in their places the necessary struts etc. were added to complete the other two sides. The tower was finished with the help of a hoist and tackle and temporary scaffolding.

The iron framework was also made ready in large sections which were put together on the spot. The specially constructed wheels are mounted in practically closed long narrow boxes (cf. *fig. 4*). Since the wheels could not be delivered quickly enough, and it was impossible to wait for them because of the lateness of the season, the framework and towers were first mounted on eight concrete blocks. It was then possible, during the construction of the towers and the putting together of the framework, to level the ground, cast the concrete walls for the tracks and to fix the I-girders and finally the rails.

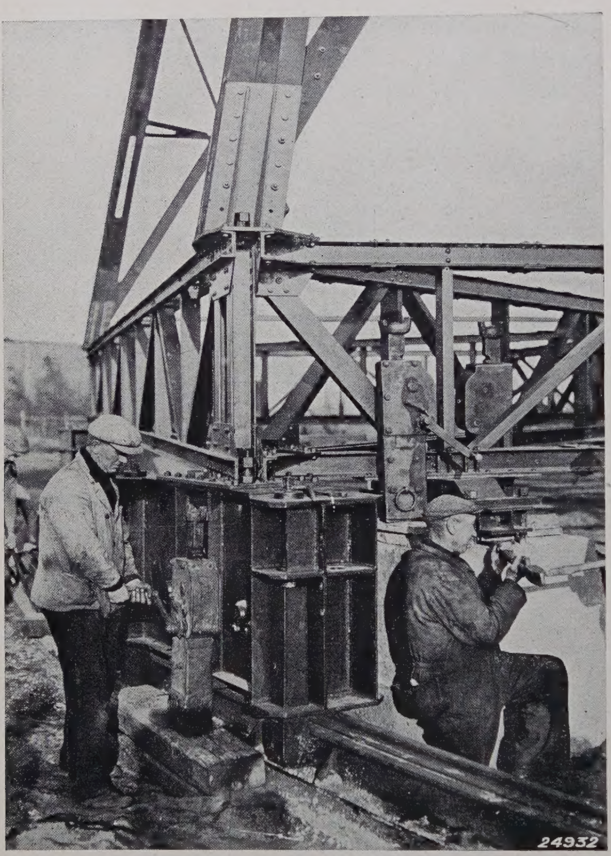

Fig. 7. The bridge with the towers is freed from the concrete blocks and rests upon the wheels.

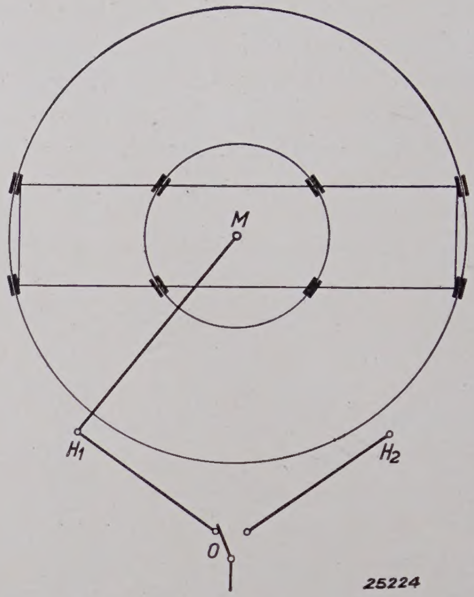

Fig. 8. Diagram of the supply of the aerial. The aerial can be fed from O *via* H_1 or H_2 to M.

The last operation was that of fastening the wheel boxes underneath the framework, and then freeing the connection between the framework and the eight concrete blocks (*fig. 7*). During this operation the framework was supported by jacks. The whole was easily lowered a distance of 0.5 cm on to the rails.

Rotation, is, for the time being, carried out by hand,

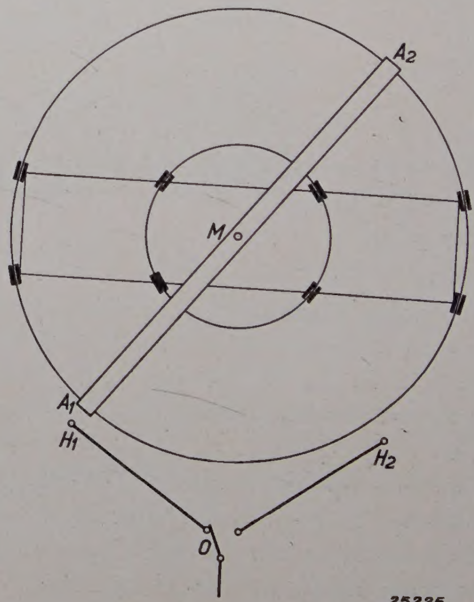

Fig. 9. Diagram showing supply circuit when using the supply arm A_1A_2, *via* H_2 or H_2 from O.

for which purpose two hand capstans are fastened underneath the framework. From each capstan a steel cable passes to a single pulley block which is fastened to a shoe on the outer rail, and from there to one of the wheel boxes. Two men at each capstan can easily set the towers in motion, while the motion can be maintained with one or two men. An electrical drive is now being designed, about which we cannot yet give any details.

The energy is supplied to the aerial vertically above the pivot by means of overhead connections. With a permanent, fixed supply connection there would be certain positions of the tower at which they would touch the supply lines or the latter would have to be conducted through the towers. By arranging the supply from two points this difficulty is avoided (*fig. 8*). In order to change from the supply point H_1 to the point H_2 the switch at *0* must be reversed and the supply line MH_1 is replaced by MH_2.

Changing the supply line is rather time-consuming, and in the long run a troublesome operation. For this reason a rotating supply arm has been designed, which can rotate independently of the towers on a pivot of its own above the framework pivot and which rests on the track. From the position drawn in *fig. 9* the towers can then be turned to the right over about 100° without the necessity of any commutation. With a greater rotation than this, the aerials must be supplied *via* H_2 by means of the other half of the rotating arm. For this purpose the switch at *0* must be reversed, the switch at H_1 opened and the rotating arm turned to the right until A_2 reaches H_2. The switch at H_2 can then be closed. *Fig. 10* gives a view of the Phohi grounds at Huizen where the PHI transmitters of the Phohi and the PCJ transmitter are set up. The new rotating directional aerial which serves for broadcasting on 31.28 m may clearly be seen at the left. In the centre background is the permanent

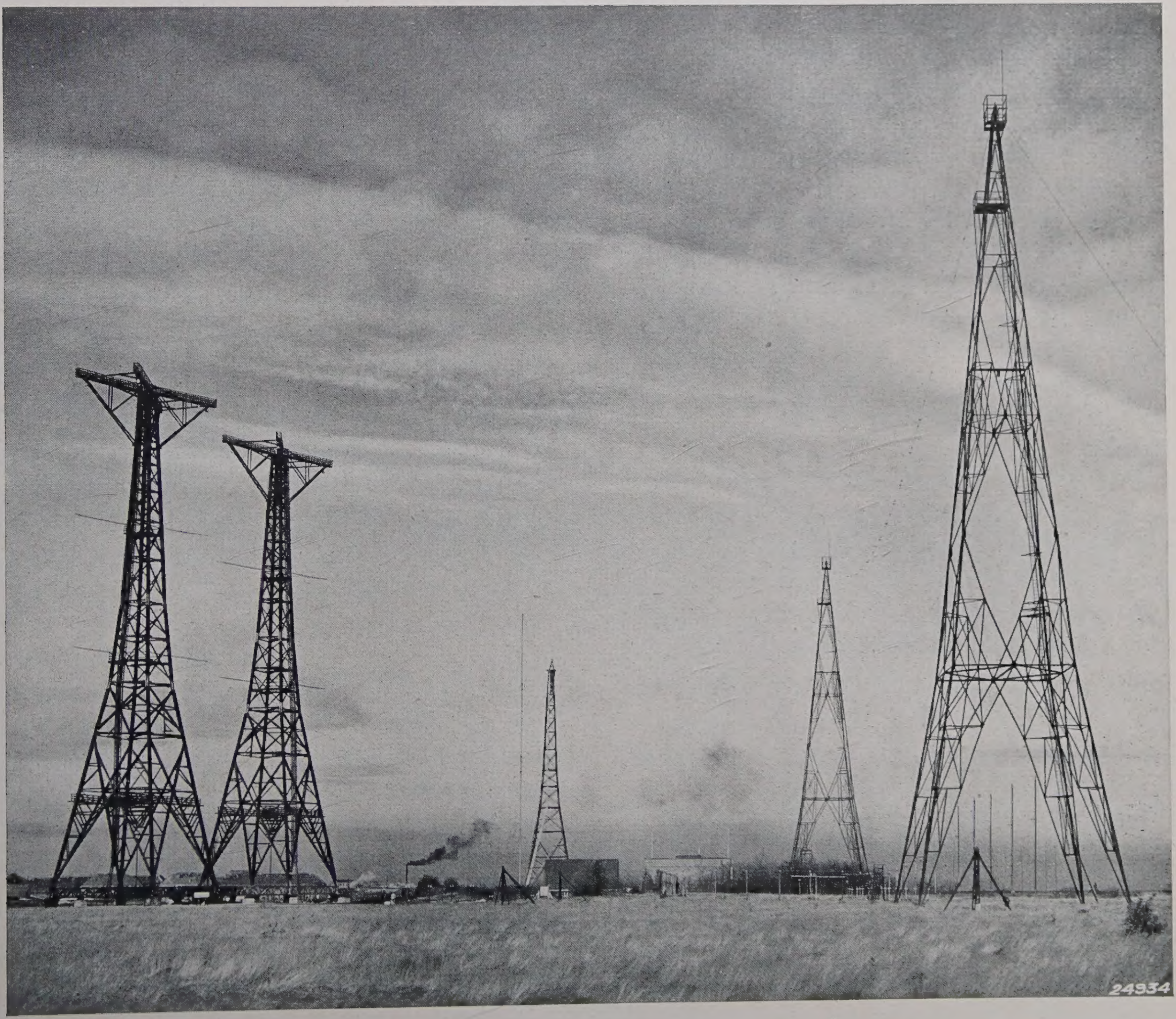

Fig. 10. General view of the grounds of the PHI transmitters of the Phohi and PCJ.

directional aerial used up to now for experimental broadcasting by PCJ on 19.71 m to the Dutch East Indies and British India. At the top of the wooden pole of this fixed directional aerial is a dipole aerial for non-directional broadcasting on either 19.71 or 31.28 m. To the right between the two high towers hangs the fixed directional aerial of the Phohi transmitter for broadcasting to the Dutch East Indies on a wave length of 16.88 m. Under the tower to the right, in the background, may be seen the fixed permanent aerial for transmission on a wave length of 25.37 m to the Dutch East Indies.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

1247*: J. van Niekerk: Anaphylaxie und Vitamin C (Act. brevia Neerl. **7**, 144 - 146, 1937).

Compare **1238** for the investigations described in this article.

1248: J. H. de Boer and E. J. W. Verwey: Semi-conductors with partially and completely filled 3*d* lattice bands (Proc. phys. Soc. **49**, extra part, 59 - 71, Aug. 1937.

Semi-conductors and insulators are discussed with incompletely filled bands of the energy levels of 3*d* electrons. If they possess a whole number of electrons per atom their lack of conductivity may be explained by the very great probability that the moving electron will be drawn back by its original atom, if only the potential barriers to be passed through are great enough to keep the probability of transition sufficiently small. If the number of electrons per atom of a definite level is not a whole number the hindrance to conduction disappears. This is the case for example in lattices of Fe_3O_4 and nickel or copper oxide when some of the places of the metal ions are unoccupied.

Substances with completely filled energy bands may become conductive as a result of irradiation with light which is capable of raising electrons into a band of higher energy. If several oxygen places in a zinc oxide lattice are empty, the excess electron in the lattice will be able to change the Zn^{++} ions into Zn^{++} ions by passing over into the energy band of the 4 s-electrons.

1249*: M. J. O. Strutt: Moderne Mehrgitter-Elektronenröhren, Erster Band: Bau, Arbeitsweise, Eigenschaften (138 pages; Julius Springer, Berlin 1937).

In a comprehensible but not too elementary way this book gives the basis of the development of radio valves with several grids. The direct stimulus to the preparation of this book was the lecture mentioned in **1148** before the Physikalische Gesellschaft Zürich.

1250: Balth. van der Pol: Television (Natuurk. voordracht Mij. Diligentia, The Hague, **15**, 36 - 45, Oct. 1937).

In this Diligentia lecture a survey was given of the present position of television. The relation to other subjects of research, such as relaxation oscillations and the theory of the rainbow was pointed out among other features.

In Nov. 1937 appeared:

Philips Transmitting News 4, No. 5:

J. P. Heyboer: The use of pentodes in radio-transmitters (continuation). Studio-equipment for League of Nations - Geneva.

M. J. Druyvesteyn and J. G. W. Mulder: Physical principles of gasfilled hot-cathode rectifiers.

In Dec. 1937 appeared:

Philips Transmitting News 4, No. 6:

J. P. Heyboer: The use of pentodes in radio-transmitters (continuation).

A rotable directional aerial for short wave world broadcasting.

P. Zijlstra: The Philips ultra short wave radio beacon type B.R.A. 075/4.

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*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.